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THE ADSORBED IONS OF COLLOIDAL CLAY AS A FACTOR IN NITROGEN FIXATION BY AZOTOBACTER[1]

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Received for publication April 8, 1939

Soil microorganisms obtain their mineral nutrients from the colloidal clay fraction, which also is active in controlling and maintaining the supply of ions. Soil microorganisms may also derive mineral nutrients by the breakdown of or exchange from the organic colloid.

Previous studies have shown that colloidal clay will serve to supply adsorbed ions to plants (1, 3) to nitrifying bacteria (2) and to legume bacteria (7, 8). The extent, however, to which the colloidal clay will nurture various microbial populations in the soil is not yet known.

The purpose of this study is to show, first, that colloidal clay will supply *Azotobacter* with adsorbed ions, the nature of which influences nitrogen fixation directly; second, that adsorbed ions in a medium exert an influence differing from the influence of ions in solution; and third, that the nature of the colloidal material alone influences nitrogen fixation.

EXPERIMENTAL

The influence of nutrients in solution and of adsorbed nutrients on colloidal clay was studied first. Electrodialyzed hydrogen clay in aqueous suspensions of 2.5 per cent served as a base to which were added different ions. All nutrients were added in the order given in table 1, and sufficient time was allowed between additions of nutrients and use to permit the reaction to reach completion.

The calcium medium, as outlined in table 1, simulated a good soil. Other variable conditions were represented in the remaining media. The magnesium media had varying amounts of magnesium with constant amounts of calcium, potassium, and phosphorus, the variation in magnesium being balanced with reciprocal variations in barium additions. The media to which the strontium had been added, as outlined, had a constant amount of calcium, potassium,

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[2] The writer wishes to express his appreciation to W. A. Albrecht, department of soils, University of Missouri, for his suggestions and for supplying the hydrogen clay; and to P. L. Gainey, department of bacteriology, Kansas State College, for his suggestions and for providing the *Azotobacter* culture used in this study.

and phosphorus, but had varying amounts of strontium and reciprocal amounts of magnesium. To 100-ml. portions of each of the media was added 2 gm. of mannitol. The media were then sterilized, inoculated with *Azotobacter*, and aerated for 3 days by forcing sterile air through the suspension.

TABLE 1

Colloidal-clay media of different mineral levels

COMPONENTS OF MEDIA		DIFFERENT MEDIA AND DESIGNATING SYMBOLS								
		Ca	Mg I	Mg II	Mg III	Mg IV	Sr I	Sr II	Sr III	Sr IV
Magnesium	m.e.	2.00								
Calcium			2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Phosphorus		4.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Potassium		3.33	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Calcium		11.93								
Barium				4.05	6.25	9.38				
Magnesium			12.50	8.45	6.25	3.12	8.45	6.25	4.05	
Strontium							4.05	6.25	8.45	12.50
Mannitol	gm.	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
H-clay		25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
Water to make 1000 ml.										

TABLE 2

Nitrogen fixed by Azotobacter *in colloidal clay with different adsorbed ions*

MEDIA	NITROGEN FIXED PER 100 ML. CLAY			pH OF MEDIUM		
	First trial	Second trial	Mean	Autoclaving		After growth
				Before	After	
	mgm.	*mgm.*	*mgm.*			
Ca	12.73	14.36	13.54	6.44	6.44	6.63
Mg I	8.68	8.73	8.70	7.15	7.15	6.60
Mg II	3.59	4.18	3.88	7.00	7.16	6.70
Mg III	2.93	2.54	2.73	7.27	7.36	6.90
Mg IV	0.37	2.05	1.21	7.44	7.49	7.24
Sr I	12.50	13.20	12.85	6.60	6.60	6.40
Sr II	14.10	.....	14.10	6.62	6.50	6.60
Sr III	13.20	13.90	13.55	6.84	6.90	6.91
Sr IV	12.50	10.60	11.55	7.05	7.10	7.05

In order to observe the influences of ions adsorbed on colloids and of ions in solution upon the fixation of atmospheric nitrogen by *Azotobacter*, Ashby's medium (4) was prepared with the following concentrations of various substances and served as a control medium throughout the experiment: mannitol, 15 gm.; $MgSO_4$, 0.2 gm.; KH_2PO_4, 0.2 gm.; NaCl, 0.2 gm.; $CaSO_4$, 0.1 gm.; $CaCO_3$, 5.0 gm.; water to make 1000 ml.

To portions of the control medium were added concentrations of from 1 to 2.5 per cent of the following colloids: H-clay, bentonite, zeolite, permutite, and norite. The H-clay colloid was usually centrifuged out of suspension and added to the Ashby's medium in concentration of 2.5 per cent. In one instance the Ashby's medium was filtered to remove all sediment, and the H-clay was added to the filtrate. Although the Ashby's filtrate originally was neutral, it became distinctly acid upon the addition of the H-clay. The medium was then brought to neutrality by the addition of NaOH.

The bentonite, permutite, norite, and zeolite colloidal systems were prepared by adding the finely divided material to Ashby's medium. The total nitrogen was determined by the Kjeldahl method. The results given in table 2 represent the mean of duplicate or quadruplicate determinations of 3 days' growth. All figures were corrected against checks.

RESULTS

The best fixation of atmospheric nitrogen by *Azotobacter* in this first experiment occurred with a high level of magnesium, in the case of the barium and magnesium series, prepared by adding only sufficient ions to replace the exchangeable hydrogen. A 25 per cent decrease of exchangeable magnesium with a similar increase of exchangeable barium decreased nitrogen fixation by 50 per cent. When the magnesium was further decreased 25 per cent, nitrogen fixation dropped an additional 25 per cent. A further decrease of magnesium resulted in some additional decrease of nitrogen fixation (table 2).

In the series of media in which there were constant amounts of calcium, potassium, and phosphorus, but variable amounts of magnesium and strontium, fixation of atmospheric nitrogen by the *Azotobacter* was approximately constant. There was a slight increase in fixation when both strontium and magnesium were present. The calcium medium also gave good nitrogen fixation.

When *Azotobacter* was grown for 3 days in Ashby's medium it was capable of fixing an average of 4.6 mgm. of nitrogen per 100 ml. of medium. The mean figure obtained here is slightly below the figures obtained by Gainey (6). Although there was considerable variation in the amount of nitrogen fixed in duplicate samples of Ashby's medium, more consistent values were obtained with the colloidal systems. The wide differences occurring in Ashby's medium alone were perhaps due to a gradual loss in the ability of the organism to fix nitrogen. When 2.5 gm. of H-clay was added to the same medium, the organism fixed 14.38 mgm. per 100 ml.—an increase of 3.1 fold.

Since Ashby's medium contained a large amount of precipitate, it was suspected that the presence of solid material might influence nitrogen fixation. In order to test this hypothesis, *Azotobacter* was grown in flasks of filtered Ashby's medium and in the same medium plus 2.5 gm. of H-clay. The amount of nitrogen fixed was 0.79 gm. per 100 ml. filtered medium, and 6.70 mgm. per 100 ml. when H-clay was added. The clay addition gave an increase of 8.5 fold. It is apparent from these results that the presence of finely divided

material has some physico chemical influence on the fixation of atmospheric nitrogen by *Azotobacter*. These data are shown in table 3.

The addition of 2 gm. of bentonite to 100 ml. of Ashby's medium resulted in a fixation of 11.24 mgm. of nitrogen as compared with only 0.83 mgm. of nitrogen in the Ashby's medium without the colloidal material. The addition of the colloidal material therefore increased nitrogen fixation 13 fold. When

TABLE 3

Nitrogen fixation in Ashby's medium in the presence and absence of colloidal H-clay

TRIALS	NITROGEN FIXED PER 100 ML. MEDIUM			
	Ashby's medium	Ashby's medium + 2.5 gm. H-clay	Filtered Ashby's medium	Filtered Ashby's medium + 2.5 gm. H-clay
	mgm.	*mgm.*	*mgm.*	*mgm.*
First	9.00	14.86	0.60	
	8.26	14.86	0.60	
Second	4.28	12.52	1.00	6.80
	2.26	12.89	0.67	6.60
Third	1.74	16.10	1.04	
	2.06	16.00		
Mean	4.60	14.38	0.79	6.70

TABLE 4

*Nitrogen fixation in Ashby's medium supplemented by various colloidal materials**

TRIALS	NITROGEN FIXED PER 100 ML. MEDIUM				
	Ashby's medium	Bentonite	Zeolite	Permutite	Norite
First	0.54	9.55	7.20	0	0
	0.40	10.40	7.45	.53	0
Second	0.66	12.32	10.10	.23	0
	1.74	12.72	9.80		0
Mean	0.83	11.24	8.64	.25	0

* Each supplement added at the rate of 2 gm. per 100 ml. Ashby's medium.

zeolite was added there was a fixation of 8.64 mgm. of nitrogen, a decrease from that in the bentonite medium, yet still more than that in Ashby's medium alone. When permutite or norite was added no significant nitrogen fixation took place, as is indicated in table 4.

DISCUSSION

The natural habitat of *Azotobacter* is the soil, where it obtains its mineral nutrients from the colloidal fraction. Thus it is reasonable to assume that

the energy necessary for the utilization of these nutrients is determined by their concentration at the surface of the colloid. It would seem probable that the mineral nutrients adsorbed at the surface of the colloid, particularly when the colloid is highly saturated, would be much more readily assimilated than those in solution and distributed at random throughout the medium. It is also possible that the colloid may in some way make a favorable physical state for the organism.

From the data, it is apparent that colloidal material influences nitrogen fixation and that the nature of the ions in the adsorption sphere of the colloid play a significant role, as is indicated below.

In Ashby's medium there are considerable insoluble calcium carbonate and some insoluble calcium phosphate. These materials, although finely divided, do not long remain suspended except when air is forced through the solution. As the results indicate, the presence of suspended material in Ashby's medium aids in the fixation of nitrogen, either through some physical factor or by replenishing ions to the solution as they are removed by the growing organisms. In the filtered Ashby's medium, where there is no insoluble precipitate to replenish ions taken by the organisms in their metabolism, the nutrients become less concentrated as the mineral needs of the organism are met. If, however, a colloidal material such as hydrogen clay or bentonite is added, the nutrients are concentrated in an available form, and nitrogen fixation is increased significantly. In the unfiltered Ashby's medium the exchange capacity of added colloid is saturated from the ions already in solution. This causes more ions to go into solution from the insoluble portion of the medium. The organism can then satisfy its mineral needs from the easily available exchangeable ions of the colloid. In the filtered Ashby's medium, apparently, insufficient ions remain to satisfy the base exchange capacity of the colloid, and for this reason the filtered medium does not function so well as does the unfiltered medium. It seems probable that the superiority of the colloidal medium over Ashby's medium may be due to the fact that the ions adsorbed at the surface of the colloid are concentrated in a limited area. The removal of a few of the adsorbed ions does not greatly influence the growth of the organism because there is still a large reserve of available ions in the adsorption sphere of the colloid.

Each gram of colloidal clay had a water of hydration content of 5.2 gm. (5). Since each 100 ml. of medium contained 2.5 gm. of clay, that means that 13 ml. of each 100 ml. was water of hydration. In other words, the entire mineral content of the 100 ml. of medium was concentrated in 13 ml. or less. It is entirely possible that the organism can obtain its mineral needs from 13 ml. more easily than it can get the same needs from 100 ml. As the data indicate, the addition of clay to Ashby's medium increased nitrogen fixation by 3.1 fold. Thus by concentrating the nutrients of the medium 7 fold on colloidal clay, the nitrogen fixation was increased 3.1 fold.

CONCLUSIONS

Colloidal clay served successfully as a basic medium for the fixation of atmospheric nitrogen by *Azotobacter*.

The amount of nitrogen fixed was influenced by the kind and quantity of ions adsorbed by the clay.

The addition of colloidal material such as colloidal clay to an aqueous medium with minerals enhanced the ability of the *Azotobacter* to fix atmospheric nitrogen.

Certain colloids when added to the Ashby's medium appeared to be more effective than others in encouraging fixation of atmospheric nitrogen by the *Azotobacter*. The order of effectiveness of those tested was as follows: clay colloid, bentonite, zeolite, permutite, norite.

Suspended solid material did not serve as effectively as colloidal material with a base exchange capacity.

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THE NITRIFICATION OF AMMONIUM THIOCYANATE (A WEED ERADICANT) AND THE EFFECT OF THIS COMPOUND UPON THE SOIL POPULATION[1]

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Received for publication April 17, 1939

In recent years interest in the use of chemical weed eradicants has increased. Sodium chlorate alone or in mixtures with other substances has been widely used and has been found effective in killing the most persistent weeds. The use of chlorate, however, requires extreme care in application because of the very decided danger of explosion and fire. Harvey (6) has suggested the use of ammonium thiocyanate, which he has found to be a useful eradicant. This compound can be made cheaply as a by-product of gas manufacture, is non-explosive, and creates no fire hazard; in addition, 18 per cent by weight of the substance is ammoniacal nitrogen, and an equal amount is cyanate nitrogen. Though there is no doubt that ammoniacal nitrogen as such, or after nitrification, is an excellent nitrogenous fertilizer, there is little information as to the availability of the nitrogen in the thiocyanate radical.

Not only should the availability of the thiocyanate nitrogen be investigated, but before ammonium thiocyanate can be recommended as a weed eradicant, later to yield nitrogenous fertilizer, studies on its toxicity to plants and also the "partial sterilization" effects on the soil should be made. Harvey has been carrying on extensive investigations on ammonium thiocyanate as a weed eradicant and on its toxic effect on the soil, together with certain other physiological aspects of the problem.

The experiments reported in this paper were carried out to determine the effect of additions of thiocyanate on the soil microflora and on the important soil biochemical processes, nitrification. It seemed that the course of the transformation of the nitrogen from the thiocyanate radical to ammonia or nitrates, which are directly available to plants as nitrogen sources, should indicate how valuable this compound might be expected to become as a nitrogen fertilizer. Pot and field experiments should follow this work.

[1] A thesis submitted by the senior author to the faculty of the Graduate School of the University of Minnesota in partial fulfillment of the requirements for the degree of master of science, June 1934. Published by permission of the director of the Minnesota Agricultural Experiment Station as Journal Series Paper No. 1543.

[2] The authors wish to express their gratitude to R. B. Harvey, who originally suggested the problem, for his kindness in allowing the use of his laboratory for certain experiments.

[3] Department of Bacteriology and Immunology and Division of Plant Pathology and Botany.

EXPERIMENTAL

Air-dried sieved soil was placed in tumblers in 200-gm. quantities. Water was added to bring the moisture content to about two-thirds saturation, which was maintained throughout the experiment. To some of the tumblers different amounts of c.p. ammonium thiocyanate or sodium thiocyanate were added with the water. As shown in the tables, various types of soil were used. At certain intervals, bacterial counts were made by Waksman's technic (9), using sodium albuminate agar as described by Fred and Waksman (2). Ten replicate plates from each dilution were usually poured, but all the plates could rarely be counted because of the prevalence of molds. No plates with any appreciable mold growth were counted.

These tumblers were incubated at 28°C. for various lengths of time. Tables 1, 2, and 3 show the results.

TABLE 1

Bacterial count (×100,000) of sandy loam garden soil

INCUBATION TIME	CONTROL	1.25 GM. NH_4CNS PER 100 GM. AIR-DRIED SOIL	1.25 GM. NaCNS PER 100 GM. AIR-DRIED SOIL
weeks			
3	71.6	21.2	36.8
5	57.6	8.4	13.0

TABLE 2

Bacterial count (×100,000) of clay garden soil

INCUBATION TIME	CONTROL	0.125 GM. NH_4CNS PER 100 GM. AIR-DRIED SOIL	0.125 GM. NaCNS PER 100 GM. AIR-DRIED SOIL
weeks			
7	68.5	50.4	46.0
9	128.8	26.0	45.0

The tables show averages of all the plates counted from the dilution. In order properly to interpret data obtained from poured plates, either all replicate counts or the values of the means and certain statistical findings should be given. Variation in counts of plates was greater than generally should be obtained. This was ascertained by using Fisher's (1) method with small samples for counts of bacterial colonies. Although variation shown by this statistical analysis is admittedly large, very few data on bacterial counts have shown less variation. In testing whether the counts from ammonium thiocyanate and sodium thiocyanate treated soils are sufficiently different from those of the untreated soil, Fisher's method of determining the significance of differences between means of small samples shows that in all cases but one, P is less than 0.01. As the highest value of P usually taken to show significance is 0.05, the results here obtained indicate that the differences for each

week between the numbers of bacteria in the thiocyanate-treated and untreated soils are significant. The only exception where P is less than 0.5 is in the 7-week period of table 2. Here there is no significant difference between thiocyanate-treated and untreated soils. It is worth noting that this one case of no significance is with soils treated with less cyanate than that applied to soils showing a depression of bacterial numbers, and with more cyanate than that applied to soils showing a stimulation. These results, then, show that in the first experiment (table 1) the thiocyanates decreased bacterial growth, and in the third experiment (table 3) they decidedly stimulated bacterial growth. Whether this stimulation is at all influenced by the calcium carbonate used in this experiment on both thiocyanate-treated and control soils, or is entirely due to the smaller amounts of thiocyanates, will have to be revealed by further experimentation.

TABLE 3

Bacterial count (×100,000) of Hempstead silt loam, 1 per cent $CaCO_3$ added

INCUBATION TIME	CONTROL	0.075 GM. NH_4CNS PER 100 GM. AIR-DRIED SOIL	0.075 GM. NaCNS PER 100 GM. AIR-DRIED SOIL
weeks			
2	88.0	207.8	183.8
6	71.7	224.0	267.0
8	131.7	243.0	279.0
10	191.0	358.6	238.7
12	129.2	302.3	206.3
14	111.4	284.0	209.5
16	63.3	289.2	152.3
18	54.7	121.5	117.5
20	65.7	146.6	136.4
22	46.8	216.4	96.6
24	42.8	167.6	156.1
26	64.8	127.5	127.9
28	51.6	129.2	121.6

After incubation, the number of algae were counted by Bristol-Roach technic (9), using the tables of probability of Halvorson and Ziegler (3, 4). Parallel with experiment 1 (table 1), where the largest quantity of thiocyanate was used, 10 replicates were made of each decimal dilution. There was neither a pronounced increase nor a decrease of algae in the treated sample. Also, by the use of Cutler's method (9) of determining total protozoa and the use of the same tables by Halvorson and Ziegler, a slightly larger number of protozoa, including cysts, were found in the treated soils than in the untreated soils. According to Halvorson and Ziegler, the differences were not significant, but the results do show that the protozoa are not decreased in such treated soils, as would be the case in a marked degree in true "partial sterilization." Later experiments will show that nitrifying bacteria were not killed, as would occur in "partial sterilization."

These experiments, then, indicate that ammonium thiocyanate increased the number of bacteria when used in amounts comparable to field practice and exerted no deleterious effect upon the soil algae and protozoa, even when used in excessively large amounts. "Partial sterilization," therefore, probably will not account for any increase in available nitrogen which the thiocyanates may cause in the soil. Any increase in ammoniacal or nitrate nitrogen must then be considered as coming from the thiocyanates added. Good growth, usually in 5 to 10 days, was found when a soil suspension was inoculated into a purely inorganic medium, with glucose as a source of energy, using distilled nitrogen-free water and sodium thiocyanate as the only source of nitrogen. These organisms were isolated by plating on the same medium agarized, and were reinoculated into the liquid medium, where heavy growth was again observed in 4 to 7 days. Thus there is no doubt that thiocyanate compounds may serve as a source of nitrogen for some organisms.

At definite periods the tumblers of Hempstead silt loam used for the bacterial counts (table 3) were emptied on clean papers, and the soil was thoroughly mixed. Ten-gram samples were used for the microbiological counts reported above. To large bottles a representative sample was added (70 gm.) in duplicate, and 140 cc. of 20 per cent sodium chloride was added. After prolonged shaking, the mixture was filtered. The treatment with sodium chloride allows the NH_4 ion to be leached out by base exchange, according to Harper (5). After filtering, a 100-cc. aliquot was analyzed for ammonia nitrogen. Nitrate nitrogen was determined in the residue by reduction with Devarda's alloy. Table 4 shows the results of these experiments.

From table 4 it will be noted that nitrification proceeded rapidly during the first few weeks of incubation. Thus it is evident that when the thiocyanates were used in amounts such as are used in practice, the nitrifying bacteria were not destroyed as in "partial sterilization." When 2 gm. rather than 0.15 gm. of the thiocyanates were added per 200 gm. of soil, nitrification was virtually stopped.

It is also evident that when ammonium thiocyanate was added to soil, only one-half of the nitrogen, on an average, was recovered as NH_3 or nitrate nitrogen, or 99.45 per cent of the nitrogen of the cation. The fluctuation of the NH_3 and nitrate nitrogen from week to week is such as is commonly found, but it seems of some significance that the fluctuations are about the 100 per cent value, the median being 100.48 per cent and the mean 99.45 per cent. The sodium thiocyanate, however, did undergo some ammonification, showing that the cyanate may become available to plants. About one-third of the N of this compound was accounted for largely as nitrates, in the latter part of the experiment, and as NH_3 in the earlier weeks. The fact that none of the anion of NH_4CNS and one third of the anion of NaCNS were accounted for as nitrate or ammoniacal nitrogen, is not surprising. Cyanates may serve as a source of N to bacteria, as was shown above, and it may also be shown that they can serve as a source of carbon, but growth is slow. When ammonium thiocyanate

TABLE 4

Nitrification in Hempstead silt loam treated with thiocyanates*

	INCUBATION TIME	NH_3-N PER GRAM SOIL	NO_3-N PER GRAM SOIL	TOTAL N (NITRATE AND AMMONIACAL)	TREATED TOTAL MINUS CONTROL TOTAL	PERCENTAGE AMMONIACAL N ACCOUNTED FOR	PERCENTAGE N IN NaCNS ACCOUNTED FOR
	weeks	*mgm.*	*mgm.*	*mgm.*	*mgm.*		
Control	2	0.0043	0.0920	0.0963			
NH_4CNS	2	0.1216	0.0870	0.2086	0.1123	77.50	
NaCNS	2	0.0170	0.0945	0.1115	0.0152		11.70
Control	4	0.0048	0.1150	0.1198			
NH_4CNS	4	0.0526	0.1862	0.2388	0.1190	82.13	
NaCNS	4	0.0124	0.1683	0.1807	0.0609		47.00
Control	6	0.0088	0.1218	0.1306			
NH_4CNS	6	0.0117	0.2356	0.2473	0.1167	80.54	
NaCNS	6	0.0124	0.1808	0.1932	0.0626		48.30
Control	8	0.0034	0.1297	0.1331			
NH_4CNS	8	0.0088	0.2699	0.2787	0.1456	100.48	
NaCNS	8	0.0114	0.1574	0.1688	0.0357		27.50
Control	10	0.0057	0.1246	0.1303			
NH_4CNS	10	0.0109	0.2955	0.3064	0.1761	121.53	
NaCNS	10	0.0091	0.1835	0.1926	0.0623		48.10
Control	12	0.0101	0.1300	0.1401			
NH_4CNS	12	0.0064	0.2929	0.2993	0.1592	109.87	
NaCNS	12	0.0064	0.1864	0.1928	0.0527		40.70
Control	14	0.0095	0.1287	0.1382			
NH_4CNS	14	0.0132	0.3129	0.3261	0.1879	129.68	
NaCNS	14	0.0131	0.1670	0.1801	0.0419		32.20
Control	16	0.0112	0.1295	0.1407			
NH_4CNS	16	0.0132	0.2826	0.2958	0.1551	107.04	
NaCNS	16	0.0125	0.1863	0.1988	0.0581		44.80
Control	20	0.0143	0.1368	0.1511			
NH_4CNS	20	0.0138	0.2936	0.3074	0.1563	107.87	
NaCNS	20	0.0102	0.1895	0.1997	0.0486		37.50
Control	22	0.0107	0.1373	0.1480			
NH_4CNS	22	0.0159	0.2635	0.2794	0.1314	90.68	
NaCNS	22	0.0237	0.1728	0.1965	0.0485		37.40
Control	24	0.0074	0.1284	0.1358			
NH_4CNS	24	0.0095	0.2983	0.3080	0.1722	118.84	
NaCNS	24	0.0129	0.1635	0.1764	0.0406		31.30

* Treatment = 0.15 gm. NH_4CNS or NaCNS per 200 gm. dry soil. NH_4CNS—theoretical amount NH_3-N added = 0.1449 mgm. per gm. soil. NaCNS—theoretical amount N added = 0.1296 mgm. per gm. soil.

TABLE 4—*Concluded*

	INCUBATION TIME	NH_3-N PER GRAM SOIL	NO_3-N PER GRAM SOIL	TOTAL N (NITRATE AND AMMONIACAL)	TREATED TOTAL MINUS CONTROL TOTAL	PERCENTAGE AMMONIACAL N ACCOUNTED FOR	PERCENTAGE N IN NaCNS ACCOUNTED FOR
	weeks	*mgm.*	*mgm.*	*mgm.*	*mgm.*		
Control	26	0.0177	0.1364	0.1541			
NH_4CNS	26	0.0183	0.2814	0.2997	0.1456	100.48	
NaCNS	26	0.0157	0.1947	0.2104	0.0563		43.40
Control	28	0.0082	0.1573	0.1655			
NH_4CNS	28	0.0136	0.2867	0.3003	0.1348	93.03	
NaCNS	28	0.0169	0.1913	0.2082	0.0427		32.90
Average NH_3 and nitrate N recovered from cation of NH_4CNS						99.45	
Average NH_3 and nitrate N recovered from NaCNS							37.10

is present, the bacteria would undoubtedly attack the more easily decomposable materials present in soil, using the ammonia necessary for metabolism. But when NaCNS is added, there would be no easily available source of N, and the thiocyanate would be attacked and NH_3 would be the by-product. When larger amounts of NaCNS were used, there was very little nitrate or ammoniacal N found in soil above that present in the control soil.

DISCUSSION

The data reveal certain facts as to the effects of thiocyanate on the soil microbial processes, although much more work is desirable on this subject. First, we can say that the algae and protozoa are not killed or reduced in number by treatment in excess of the usual field practice for weed eradication. The Rothamstad experiments have shown very definitely that when soil is subjected to the treatment known as "partial sterilization," there always results a depression in numbers so marked as to be ultimately a complete killing of algae and protozoa. These results have been confirmed a number of times (7, 10). The results here reported indicate no "partial sterilization" by thiocyanates. Even when enormous amounts of thiocyanates are incorporated in the soil, neither algae nor protozoa are killed off, nor are they reduced in number. Another result of "partial sterilization" is a sharp immediate reduction in the number of bacteria, followed by a gradual increase to numbers decidedly greater than those in untreated soil. The results here reported show a consistent and long-continued increase in bacterial population when amounts of thiocyanates such as might be used in field practice are used, and a decrease, which is maintained, when larger amounts are used. Also, it is very evident from the experiments reported that nitrifying bacteria are not killed. Nitrification proceeded promptly in all soils when treated with amounts of thiocyanates such as would be used in practice. Nitrifying bacteria are killed in

"partial sterilization." Thiocyanates, then, do not act as "partial sterilizing" agents.

The results also show that the ammoniacal nitrogen of ammonium thiocyanate can be account for largely as nitrates. This compound may be considered suitable for field and pot fertilizer trials. But the toxicity factor [which is less than that of sodium chlorate (6)] will have to be taken into consideration.

It is doubtful, however, that we can consider the CNS nitrogen directly as a very available fertilizer. Seven months after the compounds were in contact with the soil, little if any available (NH_3 and nitrate) nitrogen was found in the soil above that which could be accounted for as coming from the NH_4 radical and the soil organic nitrogen. Ammonium thiocyanate will probably be found by field trial to belong to the class of compounds which are commonly described as yielding "slowly available nitrogen." It is also indicated, but this needs confirmation, that when the "available" (nitrate and ammoniacal) nitrogen is not present, the CNS radical is indeed ammonified and nitrified, but only partially so, since, after 28 weeks, only about one-third of the nitrogen was recovered as nitrates or ammonia when NaCNS was added in amounts comparable to those of NH_4CNS that are used in field practice.

SUMMARY

When 1.25 per cent ammonium thiocyanate was added to unlimed garden soil, there was neither an increase nor a decrease in algae or protozoa.

With 1.25 per cent sodium thiocyanate or ammonium thiocyanate the number of bacteria definitely decreased in 3 and 5 weeks.

With 0.125 per cent ammonium thiocyanate there was no pronounced change in bacterial numbers in 7 weeks, but in 9 weeks there was a definite reduction.

With 0.075 per cent ammonium thiocyanate or sodium thiocyanate added to limed soil, there was always a significant increase in bacterial numbers over the control when determined at 2-week intervals up to 28 weeks.

Bacteria were isolated which grew vigorously on media the only nitrogen source of which was c.p. sodium thiocyanate.

When 1 per cent ammonium thiocyanate was added to unlimed garden soil, less than 100 per cent of the theoretical ammoniacal nitrogen could be accounted for after 2 or more weeks' incubation.

When 1 per cent sodium thiocyanate was added to unlimed garden soil, little of the theoretical thiocyanate nitrogen could be recovered as ammonia or nitrate at any time up to 7 weeks' incubation.

When 0.075 per cent ammonium thiocyanate was added to limed soil, an average of 49.7 per cent of the theoretical nitrogen (99.45 per cent of the ammonium nitrogen) was recovered in determinations every 2 weeks up to 28 weeks.

When 0.075 per cent sodium thiocyanate was added to limed soil, an average

of 37.1 per cent of the theoretical thiocyanate radical was recovered as ammonia or nitrates in determinations every 2 weeks up to 28 weeks.

Nitrification proceeded rapidly in soils treated with 0.075 per cent ammonium thiocyanate.

The application of ammonium thiocyanate in amounts used in the practice of weed eradication formed quickly available nitrogen only to one half of the nitrogen in the compound.

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EFFECT OF AMMONIUM AND NITRATE NITROGEN ON THE MINERAL COMPOSITION AND SAP CHARACTERISTICS OF BARLEY

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A previous paper (1) dealing with the ammonium and nitrate nitrogen nutrition of barley at different seasons, reported on the influence of hydrogen-ion concentration, oxygen supply, and certain metals in minute quantity on growth and development. It was found: (a) that the effect of hydrogen-ion concentration, within a physiologically tolerable range, on the growth of barley plants supplied with either ammonium or nitrate nitrogen was modified by the season of the year, and (b) that though the nitrate plants generally surpassed the ammonium plants in growth, the latter were affected extensively and favorably by either forced aeration of the culture solution or the addition of minute quantities of manganese and certain other heavy metals.

The investigation was concerned not only with the influence of the factors mentioned on the growth and development of plants as reflected in the previously reported yields (1) but also with the effects of the various treatments on the chemical composition and several characteristics of plant sap, such as conductivity, pH, and total sugars. The purpose of this paper is to present the results of these chemical studies.

METHODS AND MATERIALS

Barley plants were grown at different seasons of the year in nutrient solutions maintained within narrow limits at pH 4, 5, 6, and 6.7 respectively. A full description of the cultural methods, including the composition of the nutrient solution, was presented in an earlier article in this journal (1). Forced aeration was provided in all experiments unless otherwise indicated, by the designation "no air." The "no air" treatment in no way implies an approach to an anaerobic condition. The use of shallow tanks with loosely fitting covers permitted access of air to a large surface, providing, even in the tanks without forced aeration, an oxygen supply superior to that usually available in jars or crocks.

Each treatment was represented by 64 plants grown in the greenhouse for 5 weeks in iron tanks containing approximately 115 liters of nutrient solution.

[1] The writer gratefully acknowledges the advice received from D. R. Hoagland in the course of this investigation and wishes to thank P. R. Stout and S. B. Johnson for their assistance with part of the analytical work.

After harvest, the roots were separated from the shoots, carefully washed, and contrifuged before being weighed (9). Half of the plants from each treatment were dried at 56°C. in a ventilated oven for 72 or more hours and after being finely ground were used for total Ca, Mg, K, P, and N determinations. The remaining 32 plants were placed in tightly stoppered jars and kept in cold storage at −17° C. for later use in the determination of pH, conductivity, and total sugar concentration of the plant sap. The sap was expressed in a heavy steel screw press (9).

The following analytical methods were used:

The pH of plant sap—all pH determinations were made with the glass electrode within a few minutes after the sap was expressed.

Total sugars—the ferri-ferrocyanide method, as modified and adopted for plant materials by Hassid (5).[2]

Conductivity—Kohlrausch bridge equipped with a sound amplifier and ear-phones.

Potassium—volumetric cobalti-nitrite procedure of Hibbard and Stout (6).

Standard methods[3] were used for the determination of calcium, magnesium, nitrogen, and phosphorus. The Kjeldahl-salicylic acid method was used to determine total nitrogen of the plants in the nitrate series; and the unmodified Kjeldahl method, of those in the ammonium series. The ammonium plants were found, by a preliminary diphenylamine test, to contain no nitrates. For phosphate determinations, the volumetric procedure involving the titration of the ammonium phosphomolybdate precipitate was used.

Manganese was determined colorimetrically as permanganate by the persulfate method. To avoid metal contamination, grinding of the dried plant material was omitted. Separate samples of several grams of dried roots and shoots were weighed, ashed, and dissolved in nitric acid, and analyses were made on suitable aliquots.

EFFECT OF SOURCE OF NITROGEN ON Ca, Mg, K, P, AND N CONTENT OF PLANTS

The results of analyses of plants grown in spring (February 28 to April 2) and in fall (October 10 to November 14) are presented in figures 1 and 2. The influence of hydrogen-ion concentration on the composition of plants supplied with either ammonium or nitrate nitrogen was tested by analyzing plants grown at pH 4, 5, 6, and 6.7 respectively. The nitrate plants were found to have a higher calcium, magnesium, and potassium, but a lower phosphorus concentration than the ammonium plants. This was the case throughout the pH range studied during both the spring and fall seasons. In fall, the nitrate plants had a higher nitrogen content than the ammonium plants, but in spring the reverse was true for plants grown at pH 6.7 and only slight differences were apparent in plants grown at pH 5 and 6. Thus, no consistent relation was found between the source of nitrogen, the reaction of the nutrient solution, and the nitrogen content of the shoots.

As for the influence of the external reaction on the absorption of anions and

[2] A modification of the method has been recently published by W. Z. Hassid. *Indus. and Eng. Chem., Analyt. Ed.* 9: 228–229, 1937.

[3] Hibbard, P. L. 1932 Methods of chemical analysis. Department of Plant Nutrition, University of California. Mimeographed.

cations by the plant, the data presented in figures 1 and 2 do not point to any clear-cut relation. Although a trend toward increased cation nitrogen (ammonium) absorption with decreasing external hydrogen-ion concentration was found in case of the ammonium plants, such a relation was not in evidence during both seasons for the other cations: potassium, calcium, and magnesium. As for the anions, the phosphate concentration within the plant increased with an increase in the external pH; the nitrate plants however, had a higher total nitrogen content at pH 6.7 than at pH 5 in fall but not in spring.

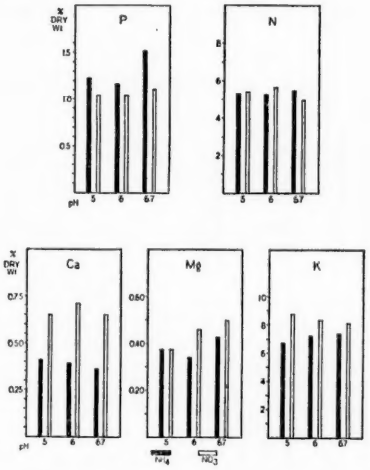

FIG. 1

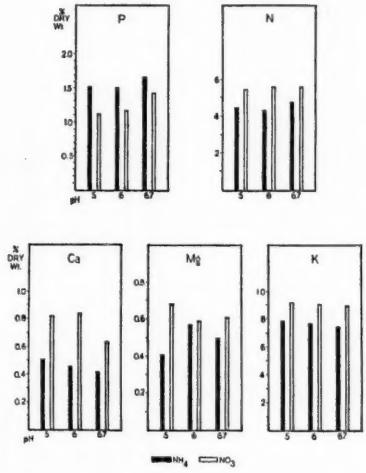

FIG. 2

FIG. 1. TOTAL Ca, Mg, K, P, AND N, EXPRESSED AS PERCENTAGES OF DRY WEIGHT OF SHOOTS OF AMMONIUM AND NITRATE PLANTS GROWN IN SPRING AT VARIOUS HYDROGEN-ION CONCENTRATIONS

FIG. 2. TOTAL Ca, Mg, K, P, AND N, EXPRESSED AS PERCENTAGES OF DRY WEIGHT OF SHOOTS OF AMMONIUM AND NITRATE PLANTS GROWN IN FALL AT VARIOUS HYDROGEN-ION CONCENTRATIONS

In view of the very distinct injury observed in plants grown at pH 4 with either form of nitrogen (1), it was deemed best not to include their composition in presenting the effect of hydrogen-ion concentration on plant composition (figs. 1 and 2). The ammonium plants at pH 4 were generally characterized, however, in agreement with the foregoing observation, by a lower base and a higher phosphorous content than the nitrate plants.

The profoundly beneficial effect of aeration and manganese on the growth of ammonium plants (1) made it desirable to determine whether the intervention of these factors has altered the relative chemical composition of ammonium and nitrate plants. Plants were grown at pH 6 with and without forced aeration or added manganese (0.5 p.p.m.). The favorable effects of manganese

and aeration on the growth of ammonium plants is shown in figure 3, graph I. The dried and finely ground shoots were analyzed for total Ca, Mg, K, P, and N. The results, presented in figure 3, indicate that aeration or added manganese, which greatly improved the growth of ammonium plants, did not alter their relative chemical composition. Thus, cation nitrogen (ammonium) was found under all conditions studied, whether favorable or unfavorable for growth, to be associated with a lower base and a higher phosphorus content, whereas supplying nitrogen in the anion (nitrate) form gave a higher base and a lower phosphorus concentration in the plant. This is in agreement with the findings of Holley, Dulin, and Pickett (10) for young cotton plants.

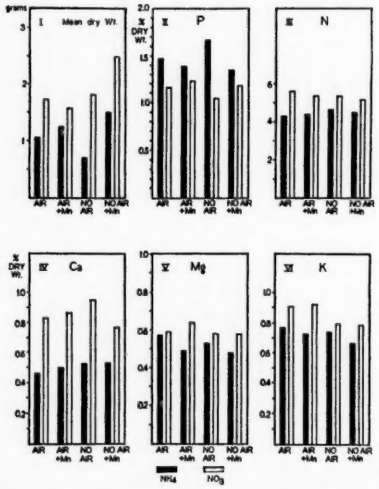

FIG. 3. EFFECT OF AERATION AND ADDITION OF MANGANESE ON GROWTH AND MINERAL COMPOSITION OF PLANTS GROWN IN FALL AT pH 6

The data presented in figures 1 and 2 describe the final composition of plants grown for an extended period and hence do not furnish direct information as to the rate of absorption of the various ions for short periods. An experimental approach to the latter problem could appropriately be made by the technic of short-time absorption experiments, using intact plants (2, 3, 14, 15), excised roots (9), or storage tissues (16).

INFLUENCE OF SOURCE OF NITROGEN ON pH, CONDUCTIVITY, AND TOTAL SUGARS OF EXPRESSED SAP

The chemical determinations on the expressed sap were carried out only on plants grown in fall. It was recognized that in expressing the sap of a root or a shoot a composite sample of several tissues is obtained and that possible alterations in one tissue resulting from an experimental treatment may be

masked by other tissues. The purpose of the following determinations was to ascertain whether, despite this difficulty of interpretation inherent in the method, some correlation existed between the several treatments and certain sap characteristics.

The pH measurements of the expressed sap are presented in table 1. The pH of the shoot sap, although somewhat lower in the ammonium than in the nitrate series, was remarkably constant except for the nitrate plants grown at pH 4, which were profoundly injured (1). In both series, the pH of the expressed root sap was found to increase slightly with increasing pH of the culture medium.

TABLE 1

Influence of external hydrogen-ion concentration on the pH of expressed sap of ammonium and nitrate plants

pH OF CULTURE SOLUTION	pH OF SAP			
	NH_4 shoots	NO_3 shoots	NH_4 roots	NO_3 roots
4	5.75	5.71	5.75	5.79
5	5.80	6.05	6.09	6.04
6	5.85	6.05	6.22	6.09
6.7	5.89	6.04	6.39	6.24

TABLE 2

Effect of aeration and added manganese on the pH of expressed sap of ammonium and nitrate plants grown at pH 6

TREATMENTS	pH OF SAP			
	NH_4 shoots	NO_3 shoots	NH_4 roots	NO_3 roots
Air	5.85	6.05	6.22	6.09
Air + Mn	5.73	6.00	6.08	6.04
No air	5.85	5.86	6.20	6.21
No air + Mn	5.77	5.87	6.08	6.08

The data presented in table 2 indicate that neither aeration nor the addition of manganese materially affected the reaction of the expressed sap of plants grown at pH 6. The significance of such small fluctuations as were noted—the lowering of the pH of the sap of ammonium plants with the addition of manganese, and the increase in the pH of the sap of nitrate plants with forced aeration—cannot be evaluated on the basis of information now available. In general the pH of the sap was found to be only slightly affected by the external hydrogen-ion concentration and by such factors as aeration and the addition of manganese. The relative constancy of the pH of sap extracted from plants grown under varied conditions is regarded as warranting emphasis.

A notable distinction between the chemical characteristics of ammonium and nitrate plants was found in determining the conductivity of the expressed

plant sap. The root sap of ammonium plants had a consistently lower conductivity than that of the nitrate plants, as shown in figures 4 and 5. The relative difference in conductivity occurred, similarly to the previously discussed differences in mineral composition, under all the experimental conditions investigated. This marked distinction between the ammonium and nitrate plants in the conductivity of expressed sap was manifest in the roots; the conductivity of the shoot sap showed relatively small fluctuations in the two series, but it was again higher in the nitrate shoots. Since the conductivity of plant saps may be affected by a number of factors other than ionic concentrations (4), the consistently higher conductivity of the root sap of nitrate as compared with ammonium plants (twice as high in many instances) would seem to justify a detailed study of the individual ionic concentrations as well as other chemical

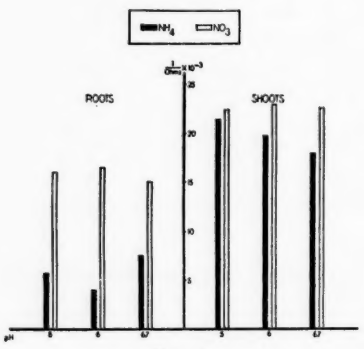

FIG. 4

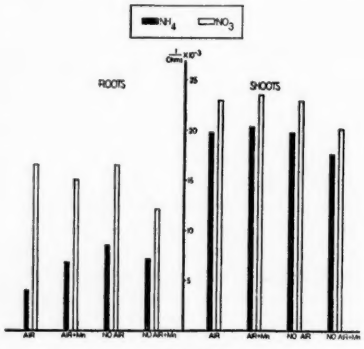

FIG. 5

FIG. 4. CONDUCTIVITY OF THE EXPRESSED SAP OF AMMONIUM AND NITRATE PLANTS GROWN IN FALL AT VARIOUS HYDROGEN-ION CONCENTRATIONS

FIG. 5. EFFECT OF AERATION AND THE ADDITION OF MANGANESE ON THE CONDUCTIVITY OF THE EXPRESSED SAP OF AMMONIUM AND NITRATE PLANTS GROWN IN FALL AT pH 6

properties of the root saps from these two different sources—an undertaking which exceeded the scope of the present investigation.

Another distinction between the ammonium and nitrate plants was found in the concentration of total sugars in the expressed sap of shoots. The ammonium plants had, under the conditions investigated, a higher sugar concentration than the nitrate plants (fig. 6). This is in agreement with the findings of Holley, Dulin and Pickett (11). Within the ammonium series, plants grown at pH 6 had a higher sugar content than those grown at any other pH value, whereas the nitrate plants showed little variation with pH.

An interesting relation between manganese and total sugar concentration was noted. The addition of manganese to the nonaerated ammonium and nitrate nutrient solutions was associated with a marked increase in the sugar concentration of the sap (fig. 6) and accompanied improved growth in both

cases (fig. 3). In the aerated cultures, however, the addition of manganese brought about a decrease in the sugar concentration, coincident with a depression in growth of the nitrate plants, but not of ammonium plants. The possible relation of manganese to carbohydrate metabolism in higher plants is now being investigated in this laboratory.

In view of the restricted growth made by the ammonium plants, it is questionable whether the higher sugar concentration found in the sap may be regarded as an indication of favorable metabolic activity. The concentration of sugars in the sap is at any given time an index not only of synthesis but also of carbohydrate utilization by the plant. A high sugar content may thus result from the absence of favorable conditions for its utilization.

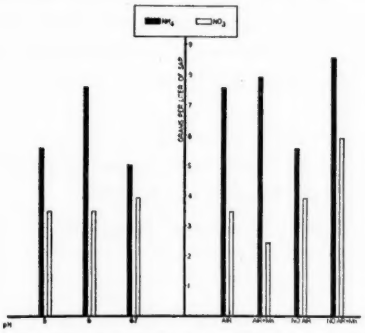

FIG. 6. TOTAL SUGARS IN THE EXPRESSED SAP OF SHOOTS OF AMMONIUM AND NITRATE PLANTS GROWN IN FALL

Left—effect of hydrogen-ion concentration.

Right—effect of aeration and the addition of manganese on plants grown at pH 6.

INFLUENCE OF AMMONIUM AND NITRATE NITROGEN ON MANGANESE CONTENT OF PLANTS

The very favorable effect of manganese on the growth of barley plants supplied with ammonium nitrogen as the sole source of nitrogen suggested a relation between the source of nitrogen and manganese nutrition. A special experiment set up at a later season to provide material for manganese analyses afforded an additional opportunity to confirm the favorable effect of aeration and manganese on the utilization of ammonium nitrogen by barley plants. Chemical analysis disclosed striking differences in the manganese content of the roots of ammonium and nitrate plants (table 3).

In every case, the roots of nitrate plants were found to contain several times as much manganese as the roots of ammonium plants. The addition of manganese to the nutrient solution (0.5 p.p.m.) brought about an enormous increase (fifty to a hundred fold) in the manganese content of the roots; but again, the nitrate plants absorbed several times as much manganese as the ammonium plants. Aeration (cf. series 2 and 4) favored the absorption of

manganese—a fact particularly marked in the case of ammonium plants, for which the manganese concentration in the aerated roots was about three times as high as that in the unaerated roots.

In contrast with the roots, the shoots of ammonium and nitrate plants, on analysis, revealed no great differences in manganese content. In the plus manganese cultures (series 2 and 4), the nitrate shoots had a higher manganese content than the ammonium shoots. In nutrient solutions without added manganese (series 1 and 3) the manganese content of the shoots of both ammonium and nitrate plants is virtually the same, except for the ammonium shoots in the unaerated cultures (series 1). Aeration increased the manganese content of ammonium shoots (series 3) to a level comparable with that of the nitrate plants, but did not alter the manganese content of the latter. As the nitrate plants also made more growth than the ammonium plants, the higher manganese content of the former is even more impressive when expressed as an amount in a plant rather than on a concentration basis.

TABLE 3

Manganese content of ammonium and nitrate plants

In p.p.m. of dry weight

SERIES	TREATMENT	NH_4 ROOTS	NO_3 ROOTS	NH_4 SHOOTS	NO_3 SHOOTS
1	No air	<3	14.5	<1	10.4
2	No air + Mn	151	1070	47.6	78.0
3	Air	<5	17.1	11.6	10.8
4	Air + Mn	540	1330	75.0	90.3

The data presented in table 3 further indicate that, although the manganese concentration of barley roots can be increased as much as a hundred fold by adding manganese to the nutrient solution (cf. series 3 and 4), it is subject to less variation in the shoots; but a high manganese concentration in the roots is associated with an increased concentration in the shoots.

The higher manganese content of nitrate roots in the minus-manganese cultures (series 1 and 3) might conceivably be attributed to greater impurities of this element in the nitrate nutrient solutions. Although no purification procedures were used in the present experiments, this possibility is considered unlikely, because of other experiments with purified nutrient salts, in which the differential responses of ammonium and nitrate plants to aeration and manganese likewise occurred (1).

DISCUSSION

The chemical investigations of barley plants reported in this paper were undertaken in order to determine whether the differential response to ammonium and nitrate nitrogen can be correlated with some modification in the chemical composition of the plant which could serve as a basis for explaining the

effect of these two sources of nitrogen on the growing plant. It was sought to ascertain, on one hand, whether some consistent modification in the mineral composition and sap characteristics can be associated with the generally poorer growth obtained with ammonium nitrogen than with nitrate nitrogen, and on the other hand, whether the observed large and favorable effect of aeration and the addition of microelements, particularly manganese, had its counterpart in some chemical change within the plant.

The presented data, referring only to several constituents of one plant species, cannot of course, by themselves serve as a basis for valid generalizations. Certain general relationships found to occur with consistency may, however, be stressed. Ammonium plants had a lower base content [cf. review by Nightingale (13)] and a higher phosphate content than nitrate plants. This, pointing to a relationship between the ionic form of nitrogen and the absorption of other ions from the culture solution, was found to hold throughout the pH range investigated, with or without forced aeration or added manganese, which favorably affected the growth of ammonium plants. It does not seem likely therefore, that this relative alteration in the mineral composition as a concomitant of ammonium absorption constitutes a necessarily unfavorable adjustment on the part of the plant. Similarly, the lower conductivity of root sap and the higher sugar content of the shoot sap of ammonium plants were found to persist even when growth was favorably influenced by forced aeration and the addition of manganese.

The manganese analyses, however, indicate a possible correlation between the absorption of this element and the differential response to the two forms of nitrogen. Nitrate plants—roots in particular—were characterized by a higher manganese content than that of ammonium plants. What is suggestive, however, is that improved growth of ammonium plants was associated with an increased manganese content; thus, both forced aeration and the addition of manganese resulted in an increased manganese content of the ammonium plant.

The question arises whether the beneficial effect of aeration on the growth of these plants may be ascribed, in part at least, to bringing about more effective absorption of such metallic microelements as manganese. This function of aeration may be of considerable importance to ammonium plants when, as in the present experiments (table 3, series 1 and 3), the manganese concentration was necessarily very small, being accounted for solely by incidental contamination of the C. P. chemicals and the distilled water used. In the absence of forced aeration, increased manganese absorption by ammonium plants, coincident with improved growth, was brought about by adding manganese to the nutrient solution.

The possibility that some manganese was either adsorbed or precipitated on the surface of the roots may raise the question whether the reported values reflect the actual concentration of maganese within the roots. Regardless of its distribution, however, the consistent difference in manganese content between the nitrate and ammonium roots is regarded as significant.

The presented data support the earlier expressed view that nitrate nitrogen may be of value to the plant in addition to serving as a source of nitrogen (1). In the present instance nitrate was found to be associated with a higher manganese content than ammonium nitrogen, particularly in the roots. This experimental finding may be explained by the stimulative effect of nitrate nitrogen on root respiration in its relation to mineral absorption [cf. discussion in (1)] or by such ionic interrelationships as are to be discussed presently, or by both.

Since different species of plants vary greatly in their requirements with respect to aeration and manganese supply, it is not to be expected that the relation of these factors to nitrogen nutrition, as reported for barley, will be encountered without modification in other plants. Tomato plants for example, as contrasted with barley, require a relatively high manganese and a liberal oxygen supply with either nitrate or ammonium nitrogen. Experiments now in progress are concerned with the relation of aeration and manganese supply to the utilization of ammonium and nitrate nitrogen in plants other than barley.

The ionic form of nitrogen in the culture solution assumes great importance in view of the very large amounts of this element used by the plant and the rapid rate of absorption of both ammonium and nitrate ions. If ammonium instead of nitrate is used as the sole source of nitrogen in the nutrient solution, a rapidly absorbable cation is substituted for a rapidly absorbable anion. The rates of absorption of phosphate and sulfate ions, the only other anions present in the ammonium nutrient solution, (except ions, such as bicarbonate, derived from the plant) are very slow (7).[4] Thus the ammonium nutrient solutions contain two rapidly absorbable cations (NH_4^+ and K^+) but no rapidly absorbable anions, whereas the nitrate nutrient solutions contain a pair of rapidly absorbable ions of opposite charge (K^+ and NO_3^-).

Although, as already pointed out, the data presented pertain to the final composition of plants grown for an extended period and hence do not furnish direct information as to the mechanism of mineral absorption, they nevertheless lend support to the view that one ion influences the absorption of another (7, 12). The lower cation and higher anion content of ammonium plants (table 4) can be attributed to such interionic effects, if it is assumed that at least part of the nitrogen is absorbed as NH_4^+. The rapid absorption of this cation would tend to depress the absorption of other cations and to increase the absorption of anions. Conversely, the rapid absorption of nitrate ion by nitrate plants would tend to depress the absorption of other anions such as phosphate, and to increase the absorption of the cations, calcium, magnesium, and potassium.

These relationships are brought out in table 4, in which the cations and

[4] Hoagland, D. R., and Broyer, T. C. Unpublished data.

anions removed by plants from the culture solution have been computed. (It is not implied, of course, that all the absorbed ions remain as ions within the plant). The phosphate was considered to have been absorbed as $H_2PO_4^-$, since this is the predominating ion throughout the pH range studied. In the ammonium plants the total nitrogen has been included in the cation fraction; and in the nitrate plants, in the anion fraction. No sulfate determinations were made, but, considering the relatively low amounts of sulfate usually found in barley plants, it appears almost certain that the inclusion of sulfates in the anion fraction would leave the relation of anions to cations, as presented in table 4, essentially unaltered.

In the ammonium plants there is a great preponderance of absorbed cations over anions. Within the plant, the electrostatic balance among the ions unincorporated in organic substances is maintained by the production of organic acid anions. In the nutrient solution, however, the excessive removal of cations is accompanied by an increase in the hydrogen-ion concentration and

TABLE 4

Total cations and anions of the shoots of ammonium and nitrate plants grown in fall

In m.e. in 100 gm. dried tissue

pH of culture solution	NH_4 shoots		NO_3 shoots	
	Total cations	Total anions	Total cations	Total anions
5	576	48.8	331	439
6	574	47.4	321	437
6.7	592	52.6	311	436

accounts for the well-known physiological acidity of nutrient media provided with ammonium salts as the sole source of nitrogen. [It is not implied, however, that ammonium nitrogen is absorbed exclusively as NH_4^+. The view that it may be absorbed, at a suitable pH, as an undissociated molecule of NH_4OH or NH_3 meets with little opposition from the adherents of the ionic conception of mineral absorption (8).]

In the nitrate plants there is, in agreement with the results of McCalla and Woodford (12), a preponderance of absorption of anions over cations, accounted for by the large absorption of nitrate nitrogen. The removal of anions in excess of cations from the nutrient solution is balanced mainly by the bicarbonate ion, derived from the plant. As suggested by Hoagland and Broyer (9), the effect is that of an exchange of bicarbonate for nitrate ion. The well-known tendency of most plants grown in acid nutrient solutions, supplied with nitrate salts as the sole source of nitrogen, to shift the external reaction toward neutrality, can be explained by the exchange of nitrate, the anion of a strong acid, for bicarbonate, the anion of a weak acid.

As for the oft discussed relation between the external hydrogen-ion concen-

tration and the absorption of cations and anions by the plant,[5] the data presented do not warrant any attempt at generalization. The absence of a consistent relationship during the two seasons of the year, between the external hydrogen-ion concentration and the absorption of the several cations, as one group, and the anions, as another, is in agreement with the view that there is little to be gained in attempting to interpret the effects of the external reaction in terms of a single variable, apart from other factors influencing the growth and metabolism of plants (1, 8, 9).

SUMMARY

Calcium, magnesium, potassium, nitrogen, and phosphorus analyses as well as determinations of pH, conductivity, and total sugars of the expressed plant sap were made on 5-week-old barley plants grown in nutrient solutions supplied with either ammonium or nitrate as the sole source of nitrogen.

The plants were grown at different seasons with control of the variables of hydrogen-ion concentration, aeration, and concentration of manganese.

Ammonium plants had, under all conditions tested, a higher phosphorus and a lower calcium, magnesium, and potassium content than nitrate plants. No consistent relation was found between the source of nitrogen, the external reaction, and the nitrogen content of the plant.

No consistent relation was found for the two seasons of the year, between the reaction of the nutrient solution and the absorption of cations versus anions.

Varying the pH of the nutrient solution within a range from pH 4 to pH 6.7 had little influence on the pH of the expressed plant sap, which remained unaltered within narrow limits.

The sap of shoots of ammonium plants had a consistently higher sugar concentration than that of nitrate plants.

The root sap of ammonium plants had a very much lower conductivity, under all conditions investigated, than the root sap of nitrate plants; the conductivity of the shoot sap varied but little between ammonium and nitrate plants.

Nitrate plants had a greater absorptive power for manganese than did ammonium plants. The possible relation of limited manganese absorption to the restriction of growth of ammonium plants is discussed.

The influence of the ionic form of nitrogen on the absorption of other ions is discussed.

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ABSORPTION OF IRON FROM FINELY GROUND MAGNETITE BY CITRUS SEEDLINGS[1]

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In connection with extensive sand culture studies, Eaton (3) found that finely ground magnetite ($FeO \cdot Fe_2O_3$) incorporated with the sand served as an excellent source of iron. These findings have been confirmed, and in the course of several years' work on problems of citrus nutrition some incidental results of interest bearing on both the iron nutrition of plants under alkaline soil conditions and the root-soil particle mechanism of nutrient absorption have been obtained. It is the purpose of this paper to describe briefly these observations.

The local zone or root-soil particle interface feeding of plants in soils is a concept commonly held among students of soil-plant interrelations. The work of older plant physiologists demonstrating the etching action of plant roots on various acid-soluble substances (2), the investigations of Parker and his coworkers (5) on phosphate nutrition, and, more recently, the studies of Jenny and Overstreet (4) on exchange absorption from clay suspensions by barley roots are but a few of the observations which indicate the probable existence of some sort of interfacial or contact feeding.

The very low solubility of magnetite in neutral or slightly acid solutions implies, as suggested by Eaton (3), that the ability of plants to obtain adequate iron from this source must depend upon the formation of intimate contacts between the root and the iron oxide particles in which conditions for the solution or extraction of iron must differ from those prevailing in the external nutrient solution.

EXPERIMENTAL

Confirmation of this inference was obtained in connection with an experiment originally set up to determine whether the traces of iron naturally present in a certain quartz sand were available for citrus seedlings.

In this experiment (subsequently referred to as experiment 1), three 2-gallon earthenware pots were filled with the quartz sand in question. Finely ground magnetite (particle sizes roughly 1 μ in diameter) at the rate of 0.1 gm. per 100 gm. of quartz sand was incorporated into two of the pots; the third was untreated. The three pots into which citrus seedlings were transplanted were periodically flushed with an iron-free nutrient solution from a common reservoir,

[1] Paper No. 400, University of California Citrus Experiment Station, Riverside, California.

the solution displaced from each pot at the time of flushing flowing back by gravity into the common reservoir. The sand cultures were flooded at hourly intervals during daylight, a time-clock controlled air-ejector pumping mechanism (1) being used to pump the solution from the reservoir to the surface of the sand cultures. Changes in the nutrient solution, due to absorption of nutrients and water, were compensated for by appropriate additions as needed, and the reaction was maintained at values fluctuating between pH 5.8 and 7.0. The solutions were completely renewed at monthly intervals.

Early in the experiment the citrus seedlings in the pot containing no magnetite developed iron chlorosis and made no further growth, whereas the plants in those pots containing magnetite showed no evidence of chlorosis and continued to grow normally. This experiment was continued for over a year, during which time the "no magnetite" plants remained alive but failed to make any growth. The relative growths made in the three pots during this period are depicted in plate 1, figure 1. Since the circulating nutrient solution passed repeatedly through the pots containing the magnetite, it is apparent that not enough iron was brought into solution, at the pH values maintained, to meet the iron requirement of the plants in the pot containing no magnetite. It is equally evident that the plant roots in the pots containing magnetite must have made intimate contact with the iron particles and developed local feeding zones.

To determine the solubility of magnetite at acidities which might conceivably develop in such zones, CO_2-free air and CO_2 gas, respectively, were bubbled through suspensions of (*a*) magnetite and water and (*b*) magnetite, calcium carbonate, and water. These suspensions were then rapidly filtered, pH determinations being made with the glass electrode just prior to filtering. Colorimetric iron determinations were made on 50-ml. aliquots of the filtrate. The results obtained (table 1) show, as was expected, that the solubility of the magnetite definitely increases with increasing H-ion concentration. This suggests that the CO_2 excreted by plant roots creates in those local zones of contact between root and iron particles a degree of acidity exceeding that of the solution external thereto and sufficient to dissolve enough iron for plant needs.

Although the foregoing evidence leaves little doubt as to local zone feeding on the magnetite particles, further observations indicate that the ability of plants to obtain adequate iron from a given quantity of this oxide is influenced by various conditions in the external nutrient medium. In a test with sand cultures containing 0.1 per cent magnetite, the addition of 2.5 per cent precipitated calcium carbonate (thoroughly mixed with the sand and magnetite) brought about iron chlorosis in citrus seedlings. The addition of more magnetite (the plants having been temporarily removed to permit the magnetite addition) made it possible for the plant again to obtain adequate iron. In order to confirm these results, this experiment was repeated.

In this latter experiment, one pot was treated first with magnetite at the

rate of 0.5 per cent, the iron oxide being thoroughly mixed with the sand. Calcium carbonate at the rate of 2.5 per cent was then added. Two other pots were treated with 0.1 per cent magnetite and 2.5 per cent calcium carbonate; in one the iron oxide being added first, in the other the calcium carbonate added first. Small sweet orange seedlings selected for uniformity were transplanted into the jars.

The cultures were flushed with nutrient solution from a common reservoir, the technic in all particulars being identical to that of experiment 1, save that no adjustments of pH were made. The results of this experiment were in complete agreement with the aforementioned tests. A picture taken during the early stages of this latter experiment showing the iron chlorosis of sweet orange seedlings in pots containing 0.1 per cent magnetite as contrasted with the normal growth in the other pot containing 0.5 per cent magnetite is shown in plate 1, figure 2.

TABLE 1

Solubility of magnetite at various pH values

NATURE OF SUSPENSION AND TREATMENT	pH OF SUSPENSION	Fe IN FILTRATE
		p.p.m.
0.1 gm. magnetite, 2.5 gm. $CaCO_3$, 100 ml. distilled water through which CO_2-free air passed	8.21	<.005*
0.1 gm. magnetite, 2.5 gm. $CaCO_3$, 100 ml. distilled water through which CO_2 gas passed	5.90	.010
0.1 gm. magnetite, 100 ml. distilled water, through which CO_2 gas passed	4.10	.500

* Not enough iron present in 50 ml. filtrate for determination. It is possible to detect as little as 0.00025 mgm. Fe in 50 ml., hence the amount present in this case must have been less than 0.005 p.p.m.

The iron chlorosis brought about by the addition of $CaCO_3$ is probably the result of the increased alkalinity of the system, and the diluting effect of the calcium carbonate. The size of the calcium carbonate particles, as examined under the microscope, was of about the same order of magnitude as that of the iron oxide particles and would diminish the total exposed surface of the magnetite by partially covering their surface.

Since it was found that by adding more magnetite to the sand the effects of the calcium carbonate were overcome, the alkalinity of the system being unchanged, it might be supposed that the diluting effect was wholly responsible for the development of chlorosis. This does not necessarily follow, however, for a decrease in solubility of the iron in the contact zones might be compensated by an increased number of contacts.

It does seem certain, from these experiments, that the iron chlorosis brought on by the addition of $CaCO_3$ with its effect on the alkalinity of the system is due to reactions or effects external to the plant root rather than to decreased

availability or immobility of the iron inside the plant; it would be difficult to explain the curative effect of increasing magnetite (the alkalinity of the system being unchanged) if inactivation of iron within the plant were the proper explanation.

That iron solubility in the contact zones is influenced by changes in the pH of the external nutrient solution is indicated by another observation made in connection with this experiment. During the course of this test, the hourly flushing of the cultures was discontinued for about 10 days while some changes in the compressed air line were being made. Curiously enough, the iron chlorotic plants in the low-magnetite pots began to recover from their chlorosis. When the hourly flushing was resumed, the plants again became chlorotic. This effect of frequent versus infrequent flooding periods was checked repeatedly, the results obtained every time being the same.

In testing the pH of the nutrient solutions under the influence of frequent versus infrequent flooding, it was invariably found that higher values prevailed with frequent flushing. Determinations of the pH of the nutrient solution draining out of the jars after continuous circulation for a 48-hour period through the sand cultures containing calcium carbonate gave values of 8.2. On the other hand, with periodic flushing at hourly intervals during daylight, the reaction of the selfsame nutrient solution dropped to values ranging from 7.3 to 7.5. With even less frequent flushing, the values dropped lower.[2] Apparently, with infrequent circulation, the carbonic acid resulting from root respiration reacts in part with calcium carbonate to form calcium bicarbonate and also accumulates to some degree as carbonic acid, causing the pH value of the entire culture solution to drop to about 7.0. With frequent circulation, on the other hand, the aeration of the solution incident to pumping decreases carbonic acid accumulation, and the pH value increases. Under the latter condition iron chlorosis develops because of the inability of the plant roots to develop enough sufficiently acid contact zones for the solution of adequate iron. The rapid removal of the CO_2 or H_2CO_3, incident to frequent flooding, which, under conditions of infrequent flushing must of necessity be higher in those somewhat vaguely defined zones surrounding the roots, would create a pH gradient between the contact zones and the external solution conducive to more rapid diffusion between these zones. These observations indicate that the contact areas between roots and soil particles, while in some measure independent, are not wholly so.

CONCLUSIONS

It was shown that the absorption of iron from finely ground magnetite, used as a source of iron in sand cultures for citrus seedlings, is made possible by the formation of intimate contacts between root and iron oxide particles in which conditions for the extraction or solution of iron must of necessity be different from those prevailing in the nutrient solution external thereto.

[2] The reaction of $CaCO_3$ suspensions through which CO_2 is being continuously bubbled will reach values as low as pH 5.6.

With an amount of magnetite sufficient under ordinary conditions (0.1 per cent), the addition of calcium carbonate brought about iron deficiency; however, with an increased amount of magnetite, the plants were again able to obtain adequate iron despite the presence of calcium carbonate. It was also found that in $CaCO_3$ cultures containing 0.1 per cent magnetite, less frequent flooding enabled the plant to obtain adequate iron, whereas frequent flooding brought on iron chlorosis. This was shown to result from pH differences developing under the variable flushing frequency technic.

The foregoing results emphasize the view that the "soil solution" consists of separate, though not altogether independent parts; one, and perhaps the most heterogeneous, those intimate contact zones between roots and all manner of soil particles; the other, the solution external thereto. Under conditions of ample moisture supply, these two phases are, to some extent at least, intercommunicating, and, by virtue of diffusion, capable of exerting mutual influences one on the other. The contacts between root surface and soil particle may exist in all degrees of intimacy, and in some, as postulated by Jenny and Overstreet (4), there may be no true solution phase, in the sense that the ions are not able to diffuse freely, being bound by the electrical forces existing at the root and soil particle surfaces.

It is probable that the number as well as the intimacy and character of the contacts is important in determining the final question of nutrient adequacy or inadequacy.

The observations reported suggest that the ability of plants to obtain adequate iron from alkaline soils is in part due to contact feeding on iron-bearing minerals. The occurrence of iron chlorosis in some calcareous soils and not in others may, in some cases, be due to differences in the amount of potentially available iron compounds present.

Under the influence of irrigation it is a common observation that iron chlorosis often develops. This may be, in part, the result of a gradual coating over of iron minerals with insoluble carbonates, the latter derived, of course, from the bicarbonate present in most irrigation waters. Increasing pH, also a result of this slow deposition of carbonate, is probably involved as well.

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PLATE 1

EFFECT OF MAGNETITE ON GROWTH OF SWEET ORANGE SEEDLINGS IN SAND CULTURES

FIG. 1. Growth of seedlings in sand cultures with and without magnetite: A, no magnetite; B and C, 0.1 per cent magnetite incorporated in sand.

FIG. 2. Growth of seedlings in sand cultures containing 2.5 per cent calcium carbonate with 0.1 and 0.5 per cent magnetite: A, green vigorously growing plants in pots containing 0.5 per cent magnetite; B and C, iron chlorotic plants in pots containing 0.1 per cent magnetite.

FIG. 1

FIG. 2

SUMMARY OF RECENT INVESTIGATIONS ON BRAZILIAN SOILS

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The following is a summary of investigations recently conducted by the author in his studies on Brazilian tropical lateritic soils and semiarid soils from northeastern Brazil.

THE ALCOXIC INDEX

It is difficult to predict the fertility of lateritic soils on the basis of ordinary types of laboratory study. Their base-exchange capacity is usually very low (0–1 m.e. per 100 gm.), and there appears to be no direct relation between base-exchange capacity of these soils and fertility. The total acid property of these soils, however, is related to fertility. An attempt has been made, therefore, to find a measure of their total acid property, which should include replaceable H ions, free acids, surface absorptive power, and amphoteric compounds. The best results were obtained by titrating a given amount of soil with alcoholic 0.1*N* NaOH. This can be done quickly and easily by the following method: Vigorously shake 5 gm. of air-dried soil with 50–100 cc. of alcoholic 0.1*N* NaOH, in a small stoppered flask. After settling 5 to 10 minutes, an aliquot of the supernatant solution is drawn off with a pipette and titrated with 0.1*N* HCl, brom thymol blue being used as indicator. The result, expressed as cubic centimeters of NaOH neutralized per 100 gm. soil, is designated the "alcoxic index." It has been found that all the tropical lateritic soils studied gave alcoxic indexes proportionate to their fertility, the more fertile soils giving indexes ranging from 400 to 800.

The relation between alcoxic index, fertility, and Hissink's *S* value are shown by the following example:

Horizon	Alcoxic index	*S* values
A	500	0.5
B	300	2.0
C	150	6.0

It is reasonable to assume that each horizon of the soil is in equilibrium with that immediately in contact with it. The supposition is logical, therefore, that as plants absorb bases from the A horizon, the bases immediately below tend to move upward. Hence, a continuous supply of bases is furnished by the deeper-lying horizons of the profile. Obviously, not all soils are characterized by such a regular increase in *S* value with depth, or by a regularly de-

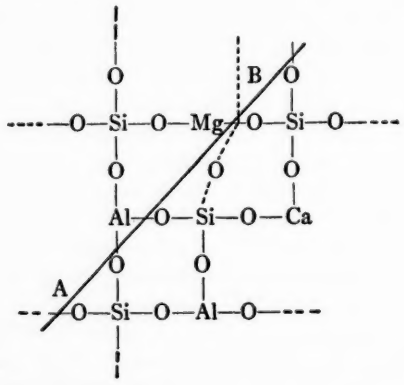
creasing alcoxic index. In fact, different tropical soils vary substantially in this respect.

The following factors influence the alcoxic index:

1. Organic matter greatly increases the alcoxic index, and the same effect is produced by grinding the soil.
2. $Al(OH)_3$, $Fe(OH)_3$, $Ti(OH)_4$, and SiO_2 increase the alcoxic index.
3. Heating to 600°C. has no effect except with soils high in humus.
4. The alcoxic index is diminished by heating the soil to 800°C. or higher.

That organic matter should increase the alcoxic index is logical because humus and cellulose react like the zeolites with reference to exchange of cations.

The increase in alcoxic index produced by grinding is comparable to that produced on the base-exchange capacity, as found by Kelley and Jenny.[1] This increase in alcoxic index is related to the effect on base-exchange capacity probably for the following reasons:



When the crystal is broken along the line A–B, the increase in base-exchange capacity is determined by the exposure of Mg, whereas the increase in H values is caused by the exposed O's which are left attached to Si. In the unbroken crystal these valences are both protected and satisfied by the adjacent oppositely charged ions.

With certain compounds grinding changes neither the base-exchange capacity nor the alcoxic index. The heteropolar constitution is altered, however, in such materials as lignin, starch, gums, and resins.

The increase in alcoxic index produced by adding $Al(OH)_3$ and other amphoteric substances is due to the formation of insoluble Na salts in the alcoholic alkaline solution. It is interesting to note that $Al(OH)_3$ acts as a monovalent

[1] Kelley, W. P., and Jenny, H. 1936 The relation of crystal structures to base exchange and its bearing on base exchange in soils. *Soil Sci.* 41: 367–382.

radical in an alcoholic solution of NaOH and can be titrated as shown by the following equation:

$$Al(OH)_3 + 4C_2H_5OH + NaOH \rightarrow \underset{\text{(alcoxic acid salt)}}{[(C_2H_5O)_4Al]Na} + 4H_2O$$

The modification of the alcoxic index by heating complex silicates to 800° C. is due to the formation of the macromolecular structure. Likewise, it is interesting to note that high temperature destroys the molecular structure of organic substances and thus lowers their alcoxic indexes.

ALKALI SOILS OF SEMIARID NORTHEASTERN BRAZIL

Acid lateritization and alkali lateritization

In various Brazilian publications[2] the author has presented his explanation of laterite and alkali soil formation. The relation of these two types of soil formation is illustrated by the following reactions:

Mineral lateritization

$$2[(SiO_3)_2Al]H \leftrightarrows [(SiO_3)_2Al]Al\begin{matrix}OH\\OH\end{matrix} + 2SiO_2$$

$$[(SiO_3)_2Al]Al\begin{matrix}OH\\OH\end{matrix} + H_2O \rightleftarrows [(SiO_3)_2Al]H + Al(OH)_3$$

The latter reaction is similar to the hydrolysis of montmorillonite:

$$Al_2O_3 \cdot 4SiO_2 \cdot H_2O + H_2O \rightleftarrows [(SiO_3)_2Al]\,H + 2SiO_2 + Al(OH)_3$$

Organic lateritization

$$[(\text{Organic Complex})\ Al]\ H + [(SiO_3)_2Al]\ H \rightleftarrows [(\text{Organic Complex})\ Al]\ Al(OH)_2 + 2SiO_2$$

$$[(\text{Organic Complex})\ Al]\ Al(OH)_2 + O_2 \rightarrow CO_2 + H_2O + Al_2O_3$$

In tropical humid climates, the instability of the free and the acid zeolitic compounds leads to the first step in laterite formation. The completion of the process involves the oxidation of the complex organic aluminum ion and other base combinations.

[2] Barreto, A. 1937–38 *Rev. Agr., S. Paulo, Brazil;* Barreto, A. 1938 Boletin das Obras Contra as Seccas.

Mineral alkali formation in the presence of organic matter

$$[(SiO_3)_2Al]\,H + NaCl \rightarrow [(SiO_3)_2Al]Na + HCl$$

In dry climates the HCl volatilizes.

$$[(SiO_3)_2Al]\,Na^3 + H_2O \rightarrow [(SiO_3)_2Al]\,H + NaOH$$

$$2NaOH + CO_2 = Na_2CO_3 + H_2O$$

Organic-alkali lateritization

$$[(\text{Organic Complex})\,Al]\,H + NaCl \rightarrow [(\text{Organic Complex})\,Al]\,Na + HCl$$

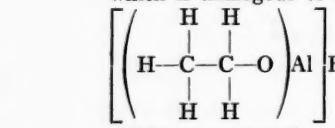
$$[(\text{Organic Complex})\,Al]\,Na + O_2 \rightarrow CO_2 + H_2O + Na_2CO_3 + Al_2O_3$$

These reactions can be produced in the laboratory, for example, by adding a solution of NaCl to an organic soil and evaporating to dryness several times, and also by oxidizing a mixture of organic soil and NaCl at 500°C.

In Brazil we find that many alkali soils give a very low alcoxic index. These soils are considered to have a very low fertility value even if freed from their alkali properties. Certain Brazilian alkali soils, relatively rich in organic matter, give high alcoxic indexes. Recently the writer determined the alcoxic indexes on a few samples of alkali soil, from areas which have been reclaimed and which are now highly productive, at the Citrus Experiment Station, Riverside, California. These gave indexes of about 300, about twice that of Brazilian alkali soils. High alcoxic index is an indication of good activity of the soil; and where such a condition exists, the reclamation of the soil should be feasible.

DISCUSSION

The alcoxic index is so designated because of the formation of Al-oxygen compounds similar to that represented by montmorillonite, $Al_2O_3 \cdot 4SiO_2 \cdot H_2O$, which is analogous to $2[(SiO_3)_2Al]H$, which in turn, can be compared with



H, alcoxic acid. The radical may be monovalent, divalent, or tetravalent, and may be combined with any base that happens to be present.

An alternate expression for the alcoxic index is *total activity* or *total activity* of the soil. We believe, however, that the method described does not give an exact measure of total activity or total acidity because some acid and some active compounds are soluble in alcohol and therefore can not be determined by this method.

By means of the alcoxic index we have sought a measure of the total activity of the soil. We believe that this index is superior to Hissink's *S* and *T* values and to Al + H values, since each of these latter refer to only a part of the soil.

[3] Blanck, E. Handbuch der Bodenlehre, Bd. 3, S. 333.

With soil from Estado da Bahia, it was found that the different horizons must have been in equilibrium insofar as S, T, and Al + H values and alcoxic indexes are concerned, as shown by the following:

A horizon	
Alcoxic index	350
Al + H value	26.5
S value	30.5
B horizon	
Alcoxic index	850
Al + H value	67.0
S value	54.3
C horizon	
Alcoxic index	650
Al + H value	46.5
S value	36.6

In several other tropical soils these values and the alcoxic index seemed, likewise, to be in equilibrium.

AN INDIRECT METHOD FOR DETERMINING THE MOISTURE CONTENT OF SOILS AT THE "STICKY POINT"

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The "sticky point" as a "single-value soil constant" has been studied by many British workers for its bearing upon tillage. A knowledge of such a physical property of the soil may be of direct help to farmers, as this constant seems to be an estimate of the maximum content of moisture for successful cultivation.

It is also known that the "sticky point" is highly correlated with many other physical properties of soils, such as loss on ignition, clay content, organic matter content, and the water content in equilibrium with an atmosphere of 50 per cent relative humidity (1). A measure of this constant, therefore, is indirectly a measure of the other properties and also gives a picture of the soil colloids.

The two methods in general use for determining the "sticky point" are that of Olmstead (3) and that of Keen and Coutts (2). The technic elaborated by Keen and Coutts is as follows: About 10 gm. of soil was spread in a thin layer on a glass plate, and distilled water was added from a fine jet until the soil was definitely wet and sticky. The mass was worked into a paste with a spatula and then scraped from the glass plate and kneaded by hand until the soil just reached the stage at which it no longer stuck to the hands or knife. The sample of kneaded soil was dried in an oven at 110°C. for 12 hours. It was weighed and the percentage of moisture calculated.

This procedure, though widely used at present, is not without defect, as seen from the following fact: In a statement made by Keen (1), when two samples of soil from the Rothamsted Station were sent to 14 stations in Europe and America for the determination of the "sticky point," the values obtained by different stations varied wide. The values of one sample ranged from 27 to 35 per cent, and those of the other had a still wider range. Because of this fact some precaution should be taken to prevent the personal error from causing such experimental difference.

It is the purpose of this paper to describe a method for locating the "sticky point," which is based upon the fact that when drops of water are slowly added to a plane surface of fine soil, a nearly hemispherical mass is formed which, if picked up and kneaded by hand, just reaches the stage at which it no longer sticks to the hands or the knife; that is, the soil is assumed to be at its "sticky point," as defined by Keen.

EXPERIMENTAL

Most of the samples used in this experiment were collected from the rice fields around Chu-yuan, in Kiangsu Province, and from Taipingmen, Nanking, and some came from Shensi Province along the Wei River. The clay content of the samples, determined by the hydrometer method of Bouyoucos, was found to vary from 21.3 to 46.4 per cent. The organic matter content, determined by the hot potassium dichromate oxidation method of Allison, was found to vary from 0.5 to 4.0 per cent.

About 50 gm. of soil was passed through a 2-mm. sieve and placed in a small wire basket, 1-cm. mesh, resting in a shallow container. The surface of the soil was made smooth by scraping it with a plate. Then 1.0 cc. of distilled water was dropped from a burette, the tip of which was 1.5 inches above the soil surface, at a rate slow enough to allow the water to soak through. Experience showed that half a minute was quite enough. The mass was left intact for another half minute. The wire basket, gently tipped to let the dry soil filter through the bottom, was then lifted from the container, and the moistened soil was picked up with a pair of glass rods and weighed immediately.

Results obtained were greatly influenced by the rate at which the water dropped and by the compactness of the sample upon which the water was added. Precautions were taken, therefore, in every determination to ensure uniform rate and compactness. In cases where the results of the second determination were not so close to the first as desired, a third determination was made; the average of the three was generally satisfactory.

On the surface of the moistened mass formed, three concentric circles of different moisture content were observed (due to the unequal rate of diffusion of the water added); namely, the circle of supersaturation upon which the water dropped, the circle of saturation in the middle, and the outermost unsaturated circle. The circles were not transitional as expected, but were rather distinct even after the soil was dry. It was also found that the amount of superfluous moisture in the innermost circle just compensated for the unsaturation of the outermost circle after the whole mass was kneaded.

In the course of the determinations of the "sticky-point" constant in these samples, a number of difficulties were encountered. It was noted that the water, when dropped upon some of the samples (nos. 9, 11, 12, 17, and 25), did not diffuse so readily as in the other samples. Upon examination of the dried mass of these five samples, a white crust formation was noted on the surface, undoubtedly indicating the presence of soluble salts in the soils which hindered the ready diffusion of water. The soluble salts were removed by stirring 100 gm. of air-dried soil in 500 cc. of distilled water for 10 minutes and then filtering through a suction funnel. After that, the samples were air-dried, and determinations were again made as described above.

The moisture content of the air-dry soil should be determined beforehand. The moisture content at the "sticky point" is obtained by dividing the weight

TABLE 1

A comparison of the percentage moisture content at the "sticky point" by the indirect method and by the method used by Keen and Coutts

SOIL NUMBER	STICKY POINT BY THE INDIRECT METHOD		STICKY POINT BY KEEN AND COUTTS' METHOD		DIFFERENCE
		Average		Average	
1	34.5 35.0	34.7	34.0 34.8	34.4	−0.3
2	36.4 36.0	36.2	35.8 35.5	35.6	−0.6
3	32.1 31.3	31.7	32.0 32.9	32.5	+0.8
4	30.4 31.2	30.8	31.0 31.0	31.0	+0.2
5	32.5 33.5	33.0	32.4 32.0	32.2	−0.8
6	35.8 36.1	35.9	34.8 35.4	35.1	−0.8
7	30.1 32.0	31.0	30.4 30.8	30.6	−0.4
8	24.6 25.0	24.8	24.0 24.3	24.2	−0.6
9*	22.0 21.0	21.5	25.8 26.0	25.9	+4.4
10	32.0 30.0	31.0	32.4 32.0	32.2	+1.2
11*	33.1 34.0	33.5	36.4 36.8	36.6	+3.1
12*	30.1 32.0	31.0	35.9 36.9	36.4	+5.4
13	36.4 37.0	36.7	36.5 36.5	36.5	−0 2
14	27.4 28.5	27.8	26.0 26.8	26.4	−1.4
15	24.5 23.0	23.7	24.2 24.8	24.6	+0.9

* Samples contain large quantities of soluble salts.

TABLE 1—*Concluded*

SOIL NUMBER	STICKY POINT BY THE INDIRECT METHOD		STICKY POINT BY KEEN AND COUTTS' METHOD		DIFFERENCE
		Average		Average	
16	30.0 32.4	31.2	28.5 29.9	29.2	−2.2
17*	30.4 31.9	31.1	35.1 36.0	35.5	+4.4
18	24.3 25.4	24.8	23.9 24.0	24.0	−0.8
19	27.4 28.3	27.8	28.0 28.2	28.1	+0.3
20	26.4 25.0	25.7	25.0 24.2	24.6	−1.1
21	29.9 27.8	28.8	28.2 26.8	27.5	+1.3
22	36.9 37.2	37.0	36.4 36.0	36.2	−0.8
23	40.1 42.0	41.0	42.0 40.3	41.1	+0.1
24	46.7 47.0	46.8	45.0 45.2	45.1	−1.7
25*	30.4 29.0	29.7	33.2 34.0	33.6	+3.9
26	43.1 43.0	43.0	43.0 43.0	43.0	0.0
27	39.2 39.1	39.1	38.7 37.2	37.9	−1.2
28	45.2 43.0	44.1	45.2 44.0	44.6	+0.5
29	33.2 34.8	33.5	34.0 33.0	33.5	0.0
30	41.0 40.0	40.5	42.0 40.1	41.0	+0.5

of 1 cc. of distilled water at the specific temperature plus the weight of moisture originally contained in the air-dry sample, by the weight of soil on an oven-dry (110°C.) basis. For general purposes, assume that 1 cc. of distilled water equals 1.0 gm. The value calculated, times 100, gives the percentage of moisture content at the "sticky point" of the particular sample.

RESULTS AND DISCUSSION

From table 1 it is seen that the results obtained by the indirect method are in agreement with those obtained by the method used by Keen and Coutts, except for those samples already mentioned, which contained an excessive amount of soluble salts. Upon the removal of the soluble salts, the figures fell into agreement with those obtained by Keen and Coutts (table 2). This

TABLE 2

Percentage moisture content at the "sticky point" after removal of soluble salts

SOIL NUMBER	STICKY POINT BY THE INDIRECT METHOD		STICKY POINT BY KEEN AND COUTTS' METHOD		DIFFERENCE
		Average		Average	
9	25.4 25.0	25.2	25.6 26.0	25.8	+0.6
11	36.0 37.1	36.5	36.4 36.8	36.6	+0.1
12	34.2 36.0	35.1	35.9 36.9	36.4	+1.3
17	36.2 36.2	36.2	35.1 36.0	35.5	−0.7
25	33.0 33.7	33.3	33.2 34.0	33.6	+0.3

indirect method has other advantages: (a) The figures obtained by this method would represent nearly the field condition because of the fact that most of the natural granules remain intact, whereas in Keen and Coutts' determination the moistened soil is brought into a single-grain or muddled condition (4, p. 209), and the paste, consisting simply of soil and water, completely saturates the colloidal gel and fills the interstices—conditions which are rarely, if ever, attained under natural field conditions; (b) it is a rapid and economic method, as the constant is directly figured from the weight of the moistened soil mass.

The only defect of the indirect method is that it cannot be used for soils containing large quantities of soluble salts, since such soils require less water to become "sticky" than do soils with small quantities of soluble salts. The

amount of decrease in "sticky point" in proportion to increase in content of soluble salts is beyond the scope of the present study. The accuracy of this method is influenced by the rate at which the water drops and by the compactness of the soil.

SUMMARY

A rapid and economical method for determining the moisture content at the "sticky point" of soils is given. Results from this method are thought to represent nearly the state of moisture content under field conditions.

Results obtained by this indirect method were comparable with those obtained by the method used by Keen and Coutts.

The only defect of this method is that it cannot be used for soils containing large quantities of soluble salts.

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FOREST SOIL STUDIES: I. RELATION OF RATE OF DECOMPOSITION OF TREE LEAVES TO THEIR ACID-BASE BALANCE AND OTHER CHEMICAL PROPERTIES[1]

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It is generally recognized that the most characteristic as well as the most important part of forest soils is the humus layer. The properties of this layer materially influence the amount of nutrients available for plant growth and, therefore, the growth and reproduction of the forest.

Although the factors affecting the development of different types of humus layers are not fully understood, it is generally believed that the tree cover plays an important role, possibly both directly and indirectly (11, 12, 13, 15, 17, 18, 23, 27). The mor type of forest humus is usually found under coniferous species and some deciduous trees, whereas the mull type is usually found under certain types of deciduous species. The reasons for these general relationships are not well established, although it is believed that the difference in the chemical composition of the leaf- and needle-fall of various species may be at least partly responsible for the differences in the humus layers formed. The properties that have been studied, mainly, are the calcium content and the acidity (1, 3, 4, 6, 7, 10, 26). These chemical properties are believed to affect the rate of decomposition of the litter and therefore the rate of liberation of nitrogen and other plant nutrients and the characteristics of the residual humus.

Romell (25), however, has recently criticized this concept of forest humus formation. According to his theory the differences in forest humus layers are not due to variations in the rate and amount of decomposition of the litter, but rather to the type of decomposition as determined by the action of different types of microorganisms. Romell contends that in mor the soil life is dominated by fungi which produce acidity, whereas in mull the fungus vegetation is relatively scarce, and bacteria play the dominant role. Very few data have been available in support of this theory. Even if it is assumed that the characteristics of the humus layer are determined by the character of the microbial population, this theory does not explain why different types of microorganisms predominate in litter from different tree species.

[1] Contribution from the department of agronomy and genetics, published with the approval of the director of the West Virginia Agricultural Experiment Station as Scientific Paper No. 217.

It is evident from these general remarks that a better understanding is needed of the various factors that determine the property of forest humus layers, and hence the productivity of forest soils. If the species of tree is an important controlling factor in determining forest-soil productivity, it is essential to obtain adequate information regarding the chemical composition of the litter of different species, their rates of decomposition, and the character of the decomposing residues.

Studies regarding the rate of decomposition of litter from different tree species have consisted mostly of field observations (6, 12, 17). Two investigations, however, have been reported of controlled studies in the laboratory. Lunt (19) studied the rate of decomposition of six hardwood species and found considerable difference among them. Melin (20), in a study of sixteen tree species, also found wide variations in decomposition, but found no correlation between such properties of the litter as pH, percentage of nitrogen, and total ash and the rate of decomposition.

Although some general relationships have been observed between the calcium content of the litter of various species and the type of humus layer developed, Plice (23), in a recent more comprehensive study containing an excellent literature review, found relatively poor agreement between the calcium content, or the calcium, magnesium, and potassium contents of the litter and the characteristics of the resulting humus.

The lack of a close relationship between such properties of the litter as its ash and calcium content, the rate of decomposition of the litter, and the nature of the residual humus is not entirely unexpected. Not only does the ash of various plants differ in content of silica, an element that has no effect on the acidity of the residue, but plants differ likewise in their content of different acidic and basic elements. Upon complete decomposition of plant materials the basicity of the residue would not be expected to be determined, therefore, by the total content of calcium but rather by the excess of the basic elements, primarily calcium, magnesium, potassium and sodium, over the acidic elements, chlorine, phosphorus and sulfur (all expressed on an equivalent weight basis).[2] Moreover, it has been shown by Waksman and coworkers (30, 31, 32), Norman (21), and others that the organic constituents of plants materially affect their rate of decomposition.

The objectives of this study are as follows: To determine the variation in the excess base, calcium, ash, H-ion concentration, nitrogen, and water-soluble organic matter of the litter of different tree species; to study the rate of decomposition of the fresh litter from different tree species under controlled conditions in the laboratory; and to determine the importance of the excess-base and other chemical properties of the litter in influencing the relative rates of decomposition of the litter from different forest-tree species.

[2] The excess of basic over acidic elements in plant materials will be referred to as "excess base" and will be expressed in milligram equivalents per 100 gm. of plant material.

GENERAL PROCEDURE AND METHODS

Samples studied

With two exceptions, the samples used in this study were collected from recently fallen leaves or from those that were mature and crisp but still attached to the tree. In collecting the leaves from the ground, care was taken to obtain only those that had recently fallen and had not been leached by rains. A brief description of the 31 samples used in this study is given in table 1. The majority of the samples were taken within a radius of 10 miles of Morgantown, West Virginia; the remaining samples, in other sections of the state. The soils from the Morgantown, Thomas, and Spencer areas are acid, unproductive silt and clay loams derived from shale and sandstone and classified in the Dekalb and Meigs series; those from Kearneysville and Hedgesville are more fertile clay loam soils derived from limestone and classified as Hagerstown silt loam. The acidity of the soils from the individual locations was not determined, but previous studies had shown that the pH of the soils in the former group ranges from about 4.8 to 5.4 and that of the soils in the latter group usually ranges from about 5.4 to 6.0.

The samples of leaves and needles were air dried and ground in a Wiley mill for the chemical and decomposition studies.

Chemical methods

The acid-base balance of the litter was determined by a method which is a slight modification of that developed by Frear (9). This consists essentially of igniting the sample for 60 minutes instead of the shorter period proposed by Frear. This assures more complete conversion of magnesium nitrate to magnesium oxide. Occasionally nitrate destruction is not complete; consequently a nitrate test is made after each ignition and if nitrates are found to be present in interfering amounts, a small quantity of carbon black is added, the solution is evaporated, and the residue is reignited.

The water-soluble organic matter was extracted by dialysis (22). One-gram samples of the leaves or needles were placed in collodion sacks inside 150-cc. extraction flasks. (The sacks had been made in 150-cc. extraction flasks.) Forty milliliters of water was put inside and 60 milliliters added outside the sack. The top of the collodion sack was folded against the side of the flask, and a stopper was inserted in such a manner that the flask could be shaken without any of the sample being lost. The flasks were shaken gently at 1-hour intervals for 6 hours and then allowed to stand for 18 hours. Fifty milliliters of the extract containing the soluble organic material was removed to a suitable weighed container (50-cc. beaker), evaporated to dryness, and weighed. The sample was then ignited and reweighed, and the difference between the two weights was taken as the weight of the water-soluble and dialyzable organic matter.

It can be seen from table 2 that the results obtained by the dialysis method

TABLE 1

Leaf samples studied for percentage decomposition and various chemical properties

LABORATORY NUMBER	SCIENTIFIC NAME	COMMON NAME	DATE SAMPLED	LOCATION	SOURCE*
1	*Acer rubrum* L.	Red maple	10–25–34	Morgantown	Ground
2	*Platanus occidentalis* L.	Sycamore	10–25–34	Morgantown	Ground
3	*Fagus grandifolia* Ehrh.	Beech	10–25–34	Morgantown	Ground
4	*Cornus florida* L.	Dogwood	10–25–34	Morgantown	Ground
6	*Quercus alba* L.	White oak	10–25–34	Morgantown	Tree
8	*Liriodendron tulipifera* L.	Yellow poplar	10–25–34	Morgantown	Ground
9	*Robinia Pseudo-Acacia* L.	Black locust	10–25–34	Morgantown	Tree
10	*Acer saccharum* March.	Sugar maple	10–25–34	Morgantown	Tree
11	*Quercus alba* L.	White oak	10–25–34	Morgantown	Tree
12	*Quercus borealis* Mishx.	Red oak	10–25–34	Morgantown	Tree
14	*Rhus hirta* Sudworth.	Staghorn sumac	10–25–34	Morgantown	Tree
15	*Fagus grandifolia* Ehrh.	Beech	10–25–34	Morgantown	Tree
16	*Sassafras variifolium*†	Sassafras	10–25–34	Morgantown	Tree
17	*Cornus florida* L.	Dogwood	10–25–34	Morgantown	Tree
18	*Acer saccharum* March.	Sugar maple	10–25–34	Morgantown	Ground
21	*Robinia Pseudo-Acacia* L.	Black locust	10–25–34	Morgantown	Tree
23	*Liriodendron tulipifera* L.	Yellow poplar	10–31–34	Morgantown	Ground
25	*Sassafras variifolium*†	Sassafras	10–31–34	Morgantown	Tree
26	*Quercus velutina* Lam.	Black oak	10–31–34	Morgantown	Tree
31	*Pinus virginiana* Mill.	Scrub pine	10–31–34	Kearneysville	Ground
32	*Pinus Strobus* L.	White pine	10–31–34	Hedgesville	Ground
35	*Platanus occidentalis* L.	Sycamore	10–19–35	Morgantown	Ground
36	*Aesculus Hippocastanum* L.	Horse chestnut	10–19–35	Morgantown	Tree
43	*Pinus rigida* Mill.	Pitch pine	10–11–35	Spencer	Tree
46	*Juglans nigra* L.	Black walnut	10–11–35	Spencer	Tree
47	*Juglans nigra* L.	Black walnut	10–11–35	Spencer	Tree
49	*Juglans nigra* L.	Black walnut	10–20–35	Spencer	Tree
51	*Juniperus virginiana* L.	Red cedar	11–12–35	Kearneysville	Tree
53	*Pinus virginiana* Mill.	Scrub pine	11–12–35	Kearneysville	Tree
55	*Quercus coccinea* Muench.	Scarlet oak	11–12–35	Kearneysville	Tree
58	*Pinus rigida* Mill.	Pitch pine	4– –36	Thomas	Tree

* All samples were well matured except nos. 9 and 21, which were slightly green.

† Salisb, Ktze.

TABLE 2

Content of water-soluble organic and inorganic material obtained by different extraction methods

SPECIES	ORGANIC MATERIAL		INORGANIC MATERIAL	
	Dialysis method	Waksman's method	Dialysis method	Waksman's method
	per cent	*per cent*	*per cent*	*per cent*
Beech	5.81	6.28	1.18	1.33
Red oak	7.59	9.96	0.58	1.09
Yellow poplar	20.68	19.56	7.31	8.29
Red maple	23.74	23.37	1.81	1.64

compare favorably with those obtained by the method developed by Waksman (29). With reasonably careful manipulation as to amount of shaking and period of dialyzing, good duplication can be obtained. This method eliminated the difficulty in filtering, which was encountered in Waksman's method, when working with samples of sassafras, oak, and maple leaves. The method is also well adapted to routine determinations.

Nitrogen was determined by the Kjeldahl method. For the determination of ash, 1-gm. samples were ignited for 5 hours at about 1000° F. Calcium was determined on the ignited ash by the regular procedure. Hydrogen-ion concentration was determined potentiometrically with the glass electrode using a 1 to 10 litter-water suspension.

Method of studying decomposition

Fifteen-gram samples of air-dry material were placed in suitable glass bottles, and the total weighed. Each was then inoculated with 1 cc. of the supernatant solution obtained by thoroughly shaking leaf mold with water and allowing the mixture to stand overnight. The leaf mold had been collected from underneath trees of most of the species studied. The sample in each bottle was then moistened to the extent of its water-holding capacity. The water-holding capacity was determined by placing 1-gm. samples into weighed Gooch crucibles containing a moist filter disk, soaking the samples in water for 24 hours, and drawing off the water by suction through the use of a water-pump. Several of the samples (Nos. 12, 16, 25, and 26) could not be satisfactorily freed from excess water, and the proper moisture content for each of these samples was therefore estimated. The amount of water used is given in the last column of table 5. After distilled water was added, the bottles were stoppered with cotton and incubated at 27–28° C. for the desired periods of time. The moisture content was maintained by adding water at irregular intervals. At the end of 2-, 4-, and 6-month periods the samples were removed from the bottles to large petri dishes to be air dried and the loss of weight determined.

EXPERIMENTAL DATA

Chemical properties of fresh litter

The chemical studies of the leaves selected for study are given in table 3. Most samples have pH values between 4.0 and 5.0, and a few pine samples have pH values below 4.0. The samples of highest pH values were yellow poplar, dogwood, horse chestnut, and black locust, one sample of the latter having a pH value of 6.68. These values are in surprisingly close agreement with those reported by Plice (23) for a number of these species.

The nitrogen content of the leaves varied from 0.46 per cent for a sample of pitch pine to 2.06 per cent for a sample of black locust. Other samples high in nitrogen are black walnut, staghorn sumac, and red cedar. Those conspicuously low are pitch pine, white pine, sugar maple, red maple, beech, and

white oak. Although there is considerable variation in some cases within a species, the differences between some of the species are very marked. Moreover, the values reported by Plice (23) for some of these species are very similar to the ones obtained in this study. Likewise, Coile (7) reported values for

TABLE 3

Chemical properties of the litter from different tree species

LABORATORY NUMBER	SPECIES	H-ION CONCENTRATION	N	WATER-SOLUBLE ORGANIC MATTER	ASH	Ca*	EXCESS BASE*
		pH	*per cent*	*per cent*	*per cent*	*m.e.*	*m.e.*
58	Pitch pine	3.46	0.57	7.7	1.94	23.4	38.2
43	Pitch pine	4.14	0.46	19.8	2.86	30.4	50.2
53	Scrub pine	3.75	1.08	11.7	2.74	19.1	40.4
31	Scrub pine	3.97	0.59	12.1	2.64	27.2	50.6
32	White pine	4.24	0.50	10.3	2.47	28.8	41.7
55	Scarlet oak	4.50	0.78	6.6	3.16	36.2	61.5
3	Beech	4.98	0.57	10.0	5.44	45.0	68.0
15	Beech	5.17	0.68	5.5	6.02	52.3	71.3
35	Sycamore	4.60	0.87	8.8	7.30	75.8	64.5
2	Sycamore	4.79	0.86	10.1	8.32	98.5	78.5
16	Sassafras	4.94	0.89	11.7	6.44	45.5	73.3
25	Sassafras	4.99	1.09	16.9	5.50	66.6	80.1
11	White oak	4.48	0.61	14.8	5.22	38.6	63.9
6	White oak	4.31	0.59	10.9	6.30	74.8	95.5
26	Black oak	4.79	0.83	13.4	3.68	41.4	88.3
51	Red cedar	4.89	1.24	9.0	5.15	73.4	99.0
12	Red oak	4.89	0.76	13.8	6.92	64.7	101.2
10	Sugar maple	4.24	0.45	20.2	8.72	84.6	107.3
18	Sugar maple	4.39	0.64	19.3	8.35	95.4	110.5
1	Red maple	4.70	0.57	26.4	8.09	86.7	113.3
8	Yellow poplar	5.19	0.74	26.2	5.32	75.4	109.6
23	Yellow poplar	5.30	0.85	23.9	6.34	97.7	131.5
14	Staghorn sumac	4.60	1.08	21.8	7.79	105.3	131.8
21	Black locust	5.24	2.06	19.8	6.04	117.4	137.5
9	Black locust	6.68	1.29	17.2	7.25	127.1	152.1
4	Dogwood	5.09	0.58	18.7	7.00	111.4	139.9
17	Dogwood	5.15	0.71	20.0	9.37	162.8	163.2
49	Black walnut	4.83	1.69	4.7	6.64	84.2	117.4
46	Black walnut	4.91	1.37	11.4	8.62	104.2	151.7
47	Black walnut	5.32	1.49	13.9	11.54	158.6	214.7
36	Horse chestnut	5.17	0.75	13.1	8.86	125.4	173.7

* Expressed as milligram equivalents per 100 gm. of the material.

red cedar, yellow poplar, and red maple which are in agreement with these figures. He obtained considerably higher values, however, for white oak and dogwood than were obtained in this study.

The percentage of water-soluble organic materials varies widely among species and also in some cases within species. Pitch pine No. 43 contained

19.8 per cent, whereas No. 58 contained only 7.7 per cent. The species with leaves particularly low in water-soluble organic materials are scarlet oak, beech, and sycamore; and those that are particularly high are sugar maple, red maple, yellow poplar, sumac, dogwood, and black locust.

The ash content of the litter of various species varied from 1.94 per cent for one of the pitch pine samples to 11.54 per cent for a sample of black walnut. The pine samples are all low in ash. Of the hardwood samples, scarlet oak (3.16 per cent) and black oak (3.68 per cent) are the lowest. Red and sugar maple, sycamore, dogwood, and black walnut contained the highest amounts. These results are in general agreement with those of other workers (2, 17, 19, 21). Joffe (17) found in his studies that the average ash content of conifers was 2.54 per cent, with a range of 1.29 to 3.31 per cent, whereas the average for hardwoods was 6.63 per cent, with a range of 3.85 to 11.74 per cent.

The calcium content of the various samples is expressed as milligram equivalents per 100 gm. of material in order to enable ready comparison of the values with those of excess base. The pine samples have a calcium content of about 25 m.e. Some of the hardwoods also are low in calcium, particularly scarlet oak, black oak, beech, sassafras, and white, red, and black oak. Intermediate in content of calcium are sycamore, red cedar, sugar maple, red maple, and yellow poplar. The species relatively high in calcium are staghorn sumac, dogwood, black walnut, black locust, and horse chestnut. A comparison of these values with those reported in the literature for certain of these species shows that the calcium content varies considerably within a species, a result apparently of site differences and other factors (1, 10, 15, 23). In spite of such variations, however, species differences are evident. For example, pines, oaks, and beech are relatively low in calcium, whereas such species as sugar maple, yellow poplar, and dogwood are generally high.

The values for excess base are given in the last column of table 3. It will be noted that the range is from 38.2 m.e. per 100 grams for a sample of pitch pine to 214.7 for a sample of black walnut. The significance of this difference can readily be understood when it is considered that upon complete decomposition the black walnut sample would liberate over five and one-half times as much base for neutralizing soil acidity as would the pitch-pine sample.

There is a general relationship between the total ash, the calcium, and the excess-base content of the different samples of litter. A statistical analysis of the data shows that the correlation is highly significant. When individual samples are considered, however, marked discrepancies are apparent. For example, samples 26, 31, and 53 contain about half as much calcium as excess base, whereas samples 2 and 35 contain more calcium than excess base. Likewise, samples 15, 16, and 35 contain approximately the same amount of ash as samples 23, 14, and 21, although the latter contain nearly twice as much excess base as the former. These variations are what may be expected, for it is well known that plants vary considerably in the relative amount of different bases and also in their contents of the acidic elements, chlorine, sulfur,

and phosphorus. Moreover, the ash content of plants varies considerably because of differences in their content of silicon, an element that has no effect on the excess-base value.

For ease of discussion the 19 species were arranged in three groups according to their excess-base values as shown in table 4.

TABLE 4

Grouping of trees with respect to the excess-base content of the leaves

GROUPS	NUMBER OF SAMPLES	SPECIES	EXCESS BASE	DECOMPOSITION AFTER 6 MONTHS
				per cent
Group 1	1	White pine	42	17
Less than 75 m.e. excess	2	Pitch pine	44	21
base per 100 gm. ma-	2	Scrub pine	46	25
terial	1	Scarlet oak	62	27
	2	Beech	70	17
	2	Sycamore	72	21
		Average	56	21
Group 2	2	Sassafras	77	45
75–110 m.e. excess base	2	White oak	80	28
per 100 gm. of material	1	Black oak	88	29
	1	Red cedar	99	40
	1	Red oak	101	36
	2	Sugar maple	109	33
		Average	92	35
Group 3	1	Red maple	113	45
More than 110 m.e. ex-	2	Yellow poplar	121	55
cess base per 100 gm. of	1	Staghorn sumac	132	60
material	2	Black locust	145	47
	2	Dogwood	152	43
	3	Black walnut	161	47
	1	Horse chestnut	174	30
		Average	143	47

Decomposition studies

The percentage decomposition of the tree leaves after 2, 4, and 6 months is reported in table 5, in which the species are arranged in the same order as in tables 3 and 4. It will be noted that the most rapid decomposition with all samples occurred during the first 2 months. This is well shown in figure 1. Many of the samples, mostly those showing a high decomposition, underwent about two-thirds as much decomposition during the first 2 months as during the whole 6-month period. A very marked difference in decomposition exists among the different species. After the 6-month period the fresh litter from

beech, sycamore, and the pines had undergone less than 25 per cent decomposition. In contrast, the litter from yellow poplar and staghorn sumac had undergone over 50 per cent decomposition. In the range of 25 to 40 per cent

TABLE 5

Amounts of decomposition and changes in pH value of litter from different tree species after various periods of time

GROUP	LABORATORY NUMBER	SPECIES	pH VALUE OF ORIGINAL LEAF MATERIAL	pH VALUE AFTER VARIOUS PERIODS OF DECOMPOSITION		DECOMPOSITION AFTER VARIOUS PERIODS			H_2O CONTENT DURING DECOMPOSITION
				4 mo.	6 mo.	2 mo.	4 mo.	6 mo.	
						per cent	*per cent*	*per cent*	*per cent*
1	58	Pitch pine	3.46	4.86	5.04	5.3	12.9	17.1	150
	43	Pitch pine	4.14	5.96	5.90	15.9	21.4	25.2	110
	53	Scrub pine	3.75	5.32	5.18	14.9	21.5	24.6	150
	31	Scrub pine	3.97	5.56	5.42	12.6	20.0	24.9	150
	32	White pine	4.24	5.56	5.32	6.0	13.0	17.2	160
	55	Scarlet oak	4.50	4.79	4.99	12.0	20.7	26.5	300
	3	Beech	4.98	6.17	6.16	7.0	12.3	17.1	250
	15	Beech	5.17	6.77	6.65	7.3	13.3	17.0	250
	35	Sycamore	4.60	5.72	5.68	7.6	14.3	17.8	220
	2	Sycamore	4.79	6.22	6.02	12.0	19.0	23.2	220
2	16	Sassafras	4.94	7.24	7.00	28.6	39.1	45.9	270
	25	Sassafras	4.99	7.26	6.85	27.6	38.0	43.4	270
	11	White oak	4.48	5.03	5.11	13.8	22.2	27.0	280
	6	White oak	4.31	5.28	5.61	12.6	22.4	28.3	280
	26	Black oak	4.79	6.40	6.25	16.0	23.3	29.1	300
	51	Red cedar	4.89	7.83	7.64	25.8	34.8	40.4	150
	12	Red oak	4.89	7.44	7.20	22.2	30.4	36.4	300
	10	Sugar maple	4.24	4.65	5.48	15.5	25.7	31.8	290
	18	Sugar maple	4.39	5.82	5.92	18.2	29.1	34.7	290
3	1	Red maple	4.70	6.72	6.98	27.5	39.5	44.9	240
	8	Yellow poplar	5.19	8.50	8.08	38.5	50.8	55.9	290
	23	Yellow poplar	5.30	8.28	8.05	36.4	48.7	53.9	290
	14	Staghorn sumac	4.60	8.54	8.77	46.6	55.8	59.5	160
	21	Black locust	5.24	8.12	8.16	34.3	43.6	49.6	200
	9	Black locust	6.68	7.52	7.60	30.6	38.2	44.4	200
	4	Dogwood	5.09	5.94	6.72	25.6	36.1	43.8	240
	17	Dogwood	5.15	4.21	5.52	25.3	34.7	41.3	240
	49	Black walnut	4.83	7.96	7.79	30.5	42.6	49.7	170
	46	Black walnut	4.91	7.15	7.33	22.8	32.8	41.6	170
	47	Black walnut	5.32	9.05	8.92	27.1	41.5	48.3	170
	36	Horse chestnut	5.17	8.57	8.64	10.4	21.1	29.8	300

decomposition are found sugar maple, horse chestnut, and the oaks; in the range of 40 to 50 per cent decomposition are sassafras, red maple, dogwood, black walnut, and black locust.

It is interesting to compare some of these values with those obtained by Lunt (19) and by Melin (20) for certain of the species. Working with leaves from six hardwood species, Lunt found during a 7-week decomposition period that the greatest loss of dry matter occurred with red maple and dogwood, and the least with beech and white oak. Sugar maple was intermediate. Melin found that red maple leaves decomposed very fast; sugar maple was intermediate; and beech, pitch pine, and white pine were slow, except one sample of white pine containing a high percentage of nitrogen. The agreement between the results obtained by these investigators and those obtained in this

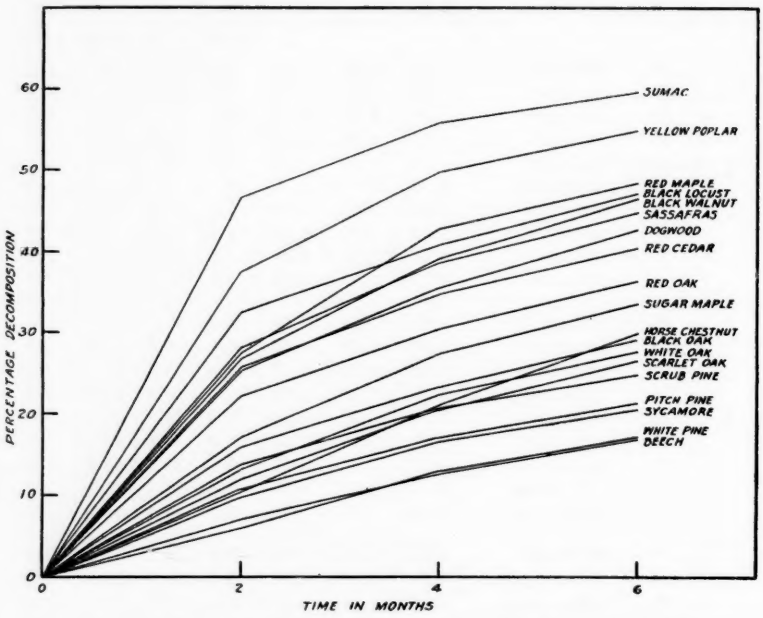

FIG. 1. AVERAGE RATE OF DECOMPOSITION OF LITTER FROM DIFFERENT TREE SPECIES

study is very significant, particularly when it is considered that the conditions were quite different in the various investigations.

The pH values of the original leaf material and of the decomposing residues after 4 and 6 months' decomposition are also given in table 5. It will be noted that the acidity of the litter decreased markedly during the first 4-month period. In many cases the increase in pH is from two to over three units. The pH values after 6 months are not very different from those after 4 months, and in a number of cases are actually lower. This can readily be explained by the relatively small amount of decomposition between 4 and 6 months and by the fact that the salt concentration was probably higher after the 6-month

period than after the 4-month period. The effect of salt concentration on the pH of certain of the samples is shown in table 6. Though differences of the order noted here would not be obtained by the increase in salt content between the 4- and 6-month periods, the principle probably applies.

It is well to note that, in general, the samples having the highest pH values after decomposition are also the ones having the highest amounts of excess base. Thus, most of the samples of group 1 with relatively low amounts of excess base had pH values below 6.0 after 6 months' decomposition, whereas those in group 3 had pH values generally above 7.5. The coefficient of correlation between the H-ion concentration of the residual humus material

TABLE 6

Effect of leaching on the pH values of leaf litter (after 4 months' decomposition)

LABORATORY NUMBER	SPECIES	pH VALUES	
		Before leaching	After leaching
58	Pitch pine	4.86	5.19
43	Pitch pine	5.96	6.27
53	Scrub pine	5.32	5.69
31	Scrub pine	5.56	5.94
32	White pine	5.56	5.90
55	Scarlet oak	4.79	5.52
3	Beech	6.16	6.79
15	Beech	6.77	6.97
11	White oak	5.03	5.58
6	White oak	5.28	5.78
35	Sycamore	5.72	6.27
2	Sycamore	6.22	6.51
16	Sassafras	7.24	7.46
25	Sassafras	7.26	7.63
26	Black oak	6.40	6.74
12	Red oak	7.44	7.64
10	Sugar maple	4.65	5.20
18	Sugar maple	5.82	6.34
14	Staghorn sumac	8.54	8.54

and the excess base of the fresh litter was found to be -0.55, a highly significant value. A very high correlation would, of course, not be expected at this stage of decomposition, since the different residues were found to have quite different base-exchange capacities.[3]

Relationship between rate of decomposition and chemical composition of litter

The relationship between the rate of decomposition of the litter of different species and their content of excess base is shown roughly in table 4. The group of low excess-base content shows an average decomposition of 21 per

[3] Unpublished data.

cent during 6 months; the intermediate group, 35 per cent; and the group of high excess-base values, 47 per cent. This relationship is seen in figure 2.

In order to determine more definitely the relationship between percentage decomposition and the excess base and other properties of the litter, the simple

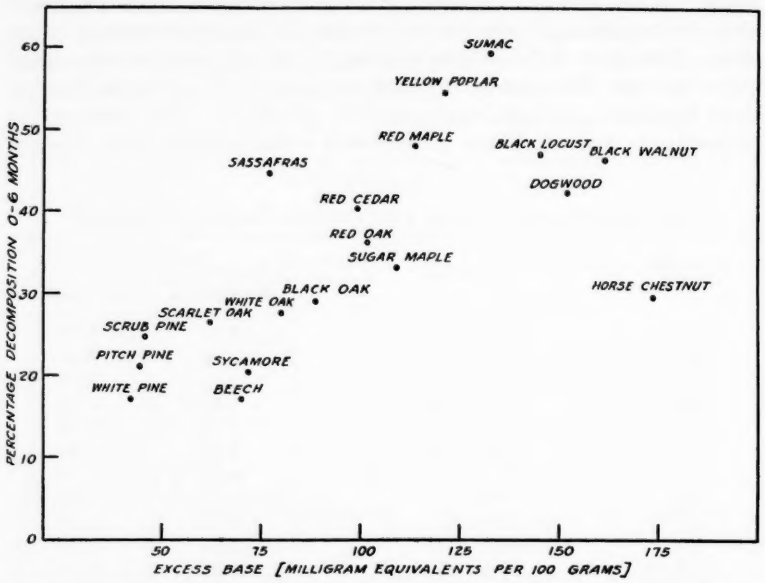

FIG. 2. RELATION BETWEEN PERCENTAGE DECOMPOSITION AND EXCESS BASE OF LITTER FROM DIFFERENT TREE SPECIES (AVERAGE VALUES)

TABLE 7

Simple coefficients of correlation between decomposition and chemical properties of tree litter

RELATIONSHIP	SYMBOL FOR RELATIONSHIP	0-6-MONTH PERIOD OF DECOMPOSITION
Percentage decomposition and excess base	r_{za}	0.672
Percentage decomposition and water-soluble organic matter	r_{zb}	0.599
Percentage decomposition and total nitrogen	r_{zc}	0.527
Percentage decomposition and total ash	r_{zd}	0.460
Percentage decomposition and total calcium	r_{ze}	0.589

The least value that can be considered *significant* is 0.355; and the least that can be considered *highly significant* is 0.456.

coefficients of correlation were first determined. These are shown in table 7. It will be noted that there is a highly significant correlation between decomposition and each of the five independent variables. The highest correlation is between excess base and percentage decomposition, the coefficient of correlation being 0.672, and the lowest is between total ash and decomposition.

A further analysis of the data by periods and also a study of the combined effect of two and of three of the independent variables on decomposition are given in table 8. During the 0–2-month period there is a highly significant correlation between decomposition, on one hand, and excess base, water-soluble organic matter, and total nitrogen on the other. During the 2–6-month period, the coefficient of correlation between decomposition and the excess-base content was 0.767, which is considerably greater than that during the

TABLE 8

Coefficients of simple and multiple correlation between decomposition and various chemical properties of tree litter

RELATIONSHIP	SYMBOL FOR RELATIONSHIP	COEFFICIENT OF CORRELATION		MINIMUM VALUES NECESSARY FOR SIGNIFICANCE*	
		0–2-month period	2–6-month period	S	H S
I. *Simple correlations:*					
Per cent decomposition and excess base.	r_{xa}	0.564	.767	0.355	0.456
Per cent decomposition and water-soluble organic matter.....	r_{xb}	0.619	.307	0.355	0.456
Per cent decomposition and per cent nitrogen.....	r_{xc}	0.522	.334	0.355	0.456
II. *Multiple correlations:*					
Per cent decomposition and excess base + water-soluble organic matter.....	$r_{x.ab}$	0.712	.767	0.439	0.530
Per cent decomposition and excess base + nitrogen.....	$r_{x.ac}$	0.772	.768	0.439	0.530
Per cent decomposition and water-soluble organic matter + N.....	$r_{x.bc}$	0.853	.478	0.439	0.530
Per cent decomposition and excess base + water-soluble organic matter + N.	$r_{x.abc}$	0.854	.768	0.498	0.582

III. *Other relationships:*

Excess base and water-soluble organic material..... $r_{ab} = 0.387$
Excess base and nitrogen..... $r_{ac} = 0.457$
Water-soluble organic material and nitrogen..... $r_{bc} = 0.101$

* The values under S are the least that can be considered significant; the values under H S are the least that can be considered highly significant.

first 2 months; whereas the coefficient of correlation with water-soluble organic material dropped from 0.619 to 0.307, and the coefficient of correlation between decomposition and percentage nitrogen dropped from 0.522 to 0.334, or below the limits of significance. It is apparent, therefore, that the influence of the nitrogen and of the water-soluble organic matter content of the litter on decomposition is exerted largely during the first 2 months, and that thereafter the decomposition is much more closely associated with the excess-base content of the litter.

The coefficients of multiple correlation between percentage decomposition and the three independent variables show that for the first 2 months there is a much better correlation between any two independent variables and percentage decomposition than between any one of them and decomposition. This is particularly so when the nitrogen and the water-soluble organic matter are considered together. If only the last 4 months are considered, however, the simple correlation between percentage decomposition and excess base is just as high as the multiple correlations ($r_{x.ab}$, $r_{x.ac}$, and $r_{x.abc}$) which take into consideration percentage nitrogen and water-soluble organic matter in addition to excess base. The coefficient of multiple correlation $r_{x.bc}$ for the 2–6 month period is found to be relatively low, 0.478, and much lower than the simple correlation between decomposition and excess base, 0.767. This again emphasizes the importance of the excess base and decomposition relationship during this 2–6-month period.

TABLE 9

Relative effects of independent variables on decomposition expressed as percentage*

VARIABLE	SYMBOL	0–2-MONTH PERIOD	2–6-MONTH PERIOD	0–6-MONTH PERIOD
Excess base.....*per cent*	A	4	97	19
H_2O-soluble organic matter.....*per cent*	B	51	1	44
Nitrogen.....*per cent*	C	45	2	37
Total.....		100	100	100

* Calculated from Standard partial regression coefficients.

The coefficient of multiple correlation between the three independent variables and percentage decomposition is 0.854 for the first period and 0.768 for the 2–6-month period.

The relative effects of the independent variables on percentage decomposition were calculated by use of the standard regression coefficients (28). The relative values expressed as precentages are given in table 9. For the entire 6-month period the relative percentage values are for excess base 19, water-soluble organic material 44, and nitrogen 37. It should be emphasized, however, that even though the relative effect of excess base is less than that of water-soluble organic matter and nitrogen, the coefficient of simple correlation for excess base and decomposition is greater, being 0.672 as compared to 0.599 and 0.527 for the other two variables. This apparent contradiction can be explained by the fact that excess base is significantly correlated with water-soluble organic matter and total nitrogen content, whereas nitrogen and water-soluble organic matter are not related.

The data of particular interest are those for the individual periods. During the 0–2-month period the water-soluble organic material and total nitrogen accounted for virtually all the explained variations in decomposition. During

the 2–6-month period, however, excess base is the determining factor, making up 97 per cent of the combined effects of all three. Percentage nitrogen and water-soluble organic matter have decreased to insignificance in this period.

These relationships can probably be explained by the chemical changes that take place as decomposition progresses and by the consequent change in flora. During the early period of decomposition the water-soluble organic constituents are readily attacked. Because of the high acidity, fungi are probably dominant and very active in this decomposition, and since they build up a large amount of fungal tissue a relatively large amount of available nitrogen is needed. Lack

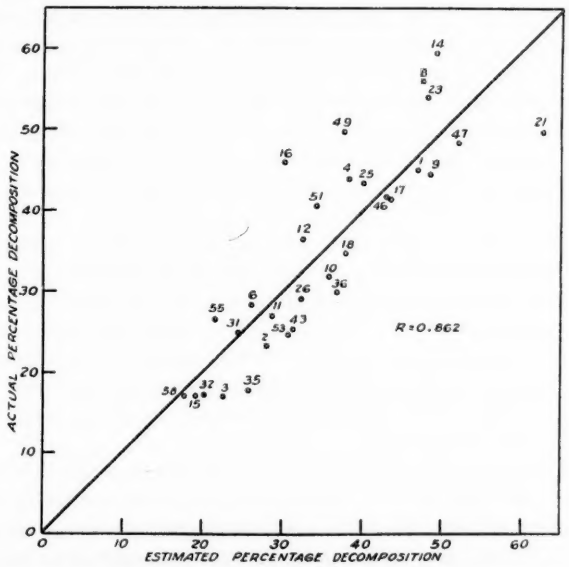

FIG. 3. PERCENTAGE DECOMPOSITION ESTIMATED FROM EXCESS BASE, PERCENTAGE OF WATER-SOLUBLE ORGANIC MATTER, AND PERCENTAGE OF NITROGEN AS INDEPENDENT VARIABLES

of nitrogen, therefore, is readily reflected in decreased rate of decomposition, which explains the correlation between nitrogen and decomposition during the first 2-month period. The lack of such correlation in the 2–6-month period is probably explained by the fact that the rate of decomposition has decreased and that bacteria rather than fungi now constitute the active microbial flora because of the lower acidity and also by the fact that there are smaller amounts of easily decomposible organic constituents. Nitrogen therefore is less of a limiting factor, and the acidity of the media, which, as is well known, influences bacterial activity, becomes more important. Since, as previously shown, the acidity of the decomposing residue is related to the excess-base content of the

original litter, a good correlation between excess base and decomposition would be expected.

From the multiple regression equation ($X = .0705A + 1.1894B + 15.680C - 2.9572$) it is possible to calculate the percentage decomposition of the various tree litters. These calculated values are plotted against the actual values in figure 3. For the 0–6-month period the multiple correlation between percentage decomposition and the three independent variables is 0.862.

GENERAL DISCUSSION

It is evident from the data obtained in this investigation that the fresh litters of different forest-tree species vary considerably in rate of decomposition. These differences are particularly significant when compared with the observed effect of these tree species on the character of the soil humus layer. The mor type of humus layer is found not only under pines and most other coniferous trees but also under many hardwood stands of oaks and beech (6, 8, 14, 16, 18, 23, 32). The latter species have been found in this investigation to produce litter which decomposes somewhat faster than pine litter but much more slowly than litter of many other hardwoods.

Griffith, Hartwell, and Shaw (12) classified a number of plots predominating in different forest-tree species into three groups, on the basis of the depth of the dark brown soil zone. The species in group A, none of which is represented in the present study, produced a deeper dark brown soil zone than those in the other groups. It is particularly significant that group B, which included soft and hard maple, generally produced deeper dark brown zones than trees in the C group of plots, which contained a preponderance of red oak, white oak, beech, white pine, and chestnut.

The high rate of decomposition of yellow poplar, black locust, dogwood, and black walnut obtained in this investigation is also in agreement with the observed effect of these species in producing a mull type of humus layer. Thus Coile (7) found that in the Duke Forest a mull type of humus layer is formed under dogwood, and a mor-like humus layer under pine and oak. Many field observations have also shown that the litter of black locust and black walnut rapidly decomposes, the residue becoming readily incorporated into the mineral soil. During the progress of a pasture survey in West Virginia it was observed that bluegrass was usually much better under these trees than in the open pasture. In the case of black locust this might be explained partly by the increased nitrogen content of the soil (13). With both species, however, the high excess-base content and the rapid rate of decomposition of the litter undoubtedly resulted in the liberation of bases and other plant nutrients favorable to the growth of Kentucky bluegrass, a species that requires a less acid and better soil than the other species present in these pastures.

The data obtained in this investigation tend to disprove Romell's theory regarding the formation of various types of forest humus layers. Romell (24, 25) contends that the rate of decomposition of the litter is not greater in the

formation of mull than in mor and that the difference in the characteristics of mull and mor is due, therefore, to the type of decomposition rather than to the rate and amount of decomposition. He believes that the type of decomposition is determined by the kind of microorganisms active in decomposition, and refers to his concept as a biological one contrasted to what he describes as the present "chemical or physico-chemical" concept. It is obvious, of course, that the so-called chemical concept, which recognizes the influence of the chemical properties of the litter in affecting rate of decomposition, does not minimize the importance of different types of microorganisms in bringing about these changes. It does emphasize, however, that variation in type of microorganisms or in their activity is a result of environmental conditions and that one of the important environmental factors is the chemical property of the litter.

One of the arguments proposed by Romell in support of his theory is that it explains more adequately than other theories the beneficial effects on the humus layer of such forestry measures as burning and green-slash manuring. Green-slash manuring is believed by him to induce a change in the type of decomposition by weakening or killing the fungi belonging to the mor vegetation. He postulates that the beneficial effect cannot be due to a higher base content, since the lime content of green needles and leaves is lower than that of mature litter. As shown in this study, however, the lime content is not the only chemical property of the litter affecting rate of decomposition. In some additional studies to be reported from this station it has been found that green leaves and needles decomposed considerably faster than mature litter, a difference at least partly explained by differences in water-soluble organic matter and other organic constituents. Green slash may therefore promote the decomposition process in the underlying litter by liberating bases and other constituents as it decomposes, which would be favorable to the activities of the microorganisms present. Similarly the beneficial effects obtained by light burning can be attributed at least partly to the liberation of bases which favorably affect rate of decomposition.

Although these data emphasize the importance of tree species in influencing the formation of forest humus layers, it should be recognized that the effect of different tree species is not independent of site. Wide variations in site conditions may affect the rate of decomposition of the litter directly through variations in moisture, temperature, and other environmental factors. Moreover, the site may indirectly influence the decomposition by influencing the chemical composition of the litter.

The good correlation obtained between certain chemical properties of the litter and the rate of decomposition is of particular interest. It emphasizes the value of chemical studies of tree litter in determining the relative effect of different species on the soil. Though field work is essential in obtaining a better understanding of soil-tree relationships, there is no question that controlled studies in the laboratory and green house can be of very much value.

This is especially evident when it is considered that under field conditions such a mixture of species exists that it is often difficult to determine the effect of individual species. Coordinated chemical, bacteriological, and physical studies, both in field and laboratory, are essential if a better understanding is to be obtained of soil-tree relationships.

SUMMARY

Thirty-one representative samples of mature undecomposed leaves and needles, representing 19 species, were studied, first in regard to differences in certain chemical properties, and second in regard to their rates of decomposition under controlled conditions. The chemical properties studied were H-ion concentration, total nitrogen, water-soluble organic matter, ash, calcium, and excess base. The decomposition as measured by loss of original material was determined after periods of 2, 4, and 6 months. Studies were made of the relationship between the chemical properties of the litter and the rate of decomposition.

The pH value of the different samples varied from 3.46 to 6.68, with most of the values below 5.0. The nitrogen content varied between 0.45 per cent for a sample of sugar maple to 2.06 per cent for a sample of black locust; the ash content, from 1.94 per cent for a sample of pitch pine to 11.54 per cent for a sample of black walnut; the calcium, from 19.1 m.e. per 100 gm. for a sample of scrub pine to 162.8 m.e. for dogwood; and the water-soluble organic matter, from 4.7 per cent for a sample of black walnut to 26.4 per cent for a sample of red maple. The excess-base content of the different samples varied from 38.2 m.e. per 100 gm. for a sample of pitch pine to 214.7 m.e. for a sample of black walnut. The values for excess base are of particular interest, since they represent the amount of base available for neutralizing soil acidity upon complete decomposition of the litter.

Although some variation exists in the chemical composition of different samples from the same species, more marked differences were found between different species and genera with respect to total nitrogen, ash, calcium, and excess base. The variations in water-soluble organic matter between different samples of the same species are considerable and may be greater than those between different species. This is probably to be expected, since a slight variation in the maturity of the sample when collected would affect the content of water-soluble organic constituents.

The pH of the residual material, in general, increased progressively as decomposition proceeded. There was no definite relationship between the pH of the original material and the pH of the residual organic matter, but a significant relationship between the latter and the excess-base content of the original litter. Those leaves high in excess base generally gave, upon decomposition, a residue of high pH value; and those low in excess base, a low pH value.

A marked difference was obtained in the rate of decomposition of fresh leaf litter from various forest-tree species when maintained under controlled condi-

tions and inoculated uniformly with a forest humus suspension. After the 6-month period, for example, the decomposition averaged less than 25 per cent for samples of pitch pine, scrub pine, white pine, beech, and sycamore; whereas it averaged over 45 per cent for samples of yellow poplar, staghorn sumac, black locust, and black walnut. Moreover, it was found that this variation in rate of decomposition is explained largely by variation in the chemical properties of the litter.

Of the properties of the litter studied, those most closely associated with rate of decomposition are water-soluble organic matter, percentage of nitrogen, and excess-base content. During the first 2 months of decomposition the first two were the controlling factors, the multiple coefficient of correlation being 0.85; whereas during the 2–6-month period the dominant factor influencing rate of decomposition was the excess-base content of the litter, the simple coefficient of correlation being 0.77.

The multiple coefficient of correlation between percentage decomposition during the 6-month period and the three independent variables—nitrogen, water-soluble organic matter, and excess base—was found to be 0.862.

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BOOKS

Principles of Organic Chemistry. By H. P. STARCK, Head of the Science Department, The Technical College, Kingston on Thames; formerly Lecturer in Chemistry, The Technical College, Bradford. Chemical Publishing Co., N. Y., 1938. Pp. viii + 664. Price $5.

This volume is a combination of a textbook and a laboratory manual in organic chemistry. Such an arrangement has a distinct advantage. The exhaustive questions at the end of each chapter are another desirable feature in a text which is designed for students taking an introductory course in organic chemistry. The author is to be congratulated on the manner of introducing the subject. He is ready to face the criticism of being too elementary. One might feel that a student beginning the study of organic chemistry should be familiar with such elementary concepts as molecular formulas and weights. The truth of the matter is that students, as a rule, fail to review their earlier courses, and a repetition is frequently a desirable feature, especially if it is, like that of the author, concise and clear. The book is well illustrated. It contains a special chapter on general tests for organic substances, a series of tables, a description of the Svedberg ultracentrifuge, and an important appendix on first aid in the laboratory.

J. S. JOFFE

The Oxidation States of the Elements and Their Potentials in Aqueous Solutions. By WENDEL M. LATIMER, Professor of Chemistry, University of California. New Prentice-Hall, Inc., 1938, Pp xiv + 352. Price $3.

The primary object of this volume, as stated by the distinguished author whose name figures prominently in calculations of free energy and entropy, "is to gather the large mass of free-energy data which is scattered throughout the literature and to present it in a simple form as an aid in the interpretation of inorganic chemistry." One should not, however, be under the impression that this volume is merely a handbook of figures. Far from it. The volume is a treatise on the subject, and all the elements are discussed in the twenty-one chapters. Any worker engaged in studies of oxidation-reduction potentials will find this book of great help.

J. S. J.

Organic Chemistry. By PAUL KARRER, Professor in the University of Zurich. Translated from the latest German edition by A. J. Mee, Head of the Science Department, Glasgow Academy. "Elsevier"—Amsterdam, Nordemann Publishing Co., Inc., New York, 1938. Pp. xx + 902. Price $11.

A unique feature of this volume is the modesty of the translator. There is

not a word from him. Apparently he felt it would be superfluous for him to justify the translation of a book on organic chemistry which since 1928, the date of the first edition, has gone through six editions.

The aim of the book as seen by the distinguished author is stated in the preface to the English translation: "To provide students with a textbook of organic chemistry of medium size which would give them a survey of the ever increasing body of facts." One might question the terminology "medium size" as applied to a volume of 902 pages. Indeed, the author covers extensively the numerous phases of organic chemistry. The subject matter is presented in a very clear and readable style.

The book is divided into four parts: Part I: Aliphatic Compounds; Part II: Carbocyclic Compounds; Part III: Heterocyclic Compounds; Part IV: Organic Compounds with Heavy Hydrogen. Part IV, naturally brief because of the newness of the subject, occupies five pages. A series of tables cover such subjects as compounds definitely present in coal-tar, arranged in order of boiling points; world production of coal, 1936; sugar production; relative sweetness of various organic substances; poisonous substances used in warfare; important dates in the history of organic chemistry. These are only a few of the many tables given. Throughout the book, special stress is laid on the description of methods of preparing the compounds and on the chemistry of the naturally occurring substances. The biological aspect of organic chemistry is thus merged with biochemistry.

There are, of course, some errors in a volume of this kind. On page 1 the author speaks of acetic acid fermentation and of the "souring of wine by the agency of acetic fungus." The microbiologist might point out that in acetic acid fermentation the bacteria are the agents, not the fungi. This error simply means that an organic chemist need not necessarily be a microbiologist.

The book is a worthwhile addition to our stock of translations of scientific contributions from foreign languages.

J. S. J.

The Chemical Formulary. A collection of valuable, timely, practical commercial formulas and recipes for making thousands of products in many fields of industry. Volume IV. H. BENNETT, Editor-in-chief. Chemical Publishing Co., New York, 1939. Pp. 638. Price $6.

The purpose of this publication is indicated by the subtitle. The book contains a wealth of recipes collected from various sources, of which the editor appropriately says: "Since these sources are often subject to various errors and omissions, due regard must be given to this factor." Many odd things one would not even think of may be found in this volume. In the section "Farm and Garden," the reviewer found such an oddity in the following formula for a soil conditioner: "coal ground to pass a screen of approximately 40 to 70 mesh and roasted at a temperature between 300 and 400 degrees F." What

this formula and another containing "rock salt" will do to the soil is not stated. The volume even has formulas for the latest fad on hydroponics or "soilless growing nutrient salts." A soil scientist would not advise use of the "Farm formulas" without reservations and without consultation with an expert. The editor justly forsees such circumstances and advises the reader to "arrange for the services of a chemist or technical worker familiar with the specific field in which he is interested."

J. S. J.

Annual Review of Biochemistry. Volume VIII. JAMES MURRAY LUCK, Editor, Stanford University, and JAMES H. C. SMITH, Associate Editor, Carnegie Institution of Washington, Division of Plant Biology, Stanford University, California. Annual Reviews, Inc. Stanford University P. O., California, 1939. Pp. ix + 676. Price $5.

The wide scope of these now famous "Annual Reviews" may be judged from the table of contents, which follows: Biological Oxidations and Reductions; Proteolytic Enzymes; Nonproteolytic Enzymes; Polysaccharides and Lignin; X-Ray Studies of the Structure of Compounds of Biological Interest; The Chemistry of the Acyclic Constituents of Natural Fats and Oils; The Chemistry of Proteins and Amino Acids; The Chemistry and Metabolism of the Compounds of Sulfur; Carbohydrate Metabolism; Lupid Metabolism; Metabolism of Proteins and Amino Acids; Mineral Metabolism. Calcium, Magnesium, and Phosphorus; Hormones; Choline as a Dietary Factor; The Water-Soluble Vitamins; Fat-Soluble Vitamins; Metabolism of Brain and Nerve; The Alkaloids; Chemical Aspects of Photosynthesis; Mineral Nutrition of Plants; Growth Hormones in the Higher Plants; Animal Poisons; Ruminant Nutrition; Immunochemistry; The Biochemistry of Yeast.

This volume is a worthy successor to the volumes of other years. The cosmopolitan nature of the Reviews is evident from the fact that eleven of the twenty-five papers are from foreign countries. To the specialists in the various fields of biochemistry these reviews are an invaluable aid.

J. S. J.

Utilization of Fats. By H. K. DEAN. With a foreword by T. P. Hilditch, Campbell-Brown Professor of Industrial Chemistry at the University, Liverpool. Chemical Publishing Co., New York, 1938. Pp. xiv + 292. Price $6.

In a field of study which is in the process of expansion and development, as is the study of fats, a new volume is a welcome addition. The new theoretical aspects of the subject, especially the physicochemical reactions, have been incorporated in this volume. This makes the publication more valuable both from the theoretical and the applied side of the subject. The industrial applications of fatty materials and their derivatives form the main body of information in the following chapters: I. Constituents and Properties of Fats;

II. Analytical Methods; III. Classification, Composition, and Analysis of Fats; IV. Artificial Fats; V. Extraction and Refining of Fats; VI. Edible Fats; VII. Paint and Varnish Oils; VIII. Soaps and Fatty Acids; IX. Miscellaneous Applications.

By the use of small-sized type, the publishers, who are the exclusive agents for this book in North and South America, economized on the number of pages but not on the subject matter.

J. S. J.

Grundriss der tropischen und subtropischen Bodenkunde (An outline of Tropical and Subtropical Soils). Zweite, vermehrte Auflage. By P. VAGELER. Verlagsgesellschaft für Ackerbau m.b.h., Berlin, 1938. Pp. 252. Preis des Leinenbande RM 12.75.

The second, somewhat enlarged, edition of this scholarly monograph includes data on the tropical soils of Asia, Africa, and South America. A noteworthy feature of Dr. Vageler's work is that the author speaks authoritatively from personal experience. In the first edition he wrote about his studies in the tropics of Asia and Africa. In this edition he has added his observations on South America. He is associated now with the Agricultural Tropical Research Institute in Brazil, Instituto Agronomico de Estado de Sao Paulo in Campinas. The first edition was translated into English, and it is hoped that the second edition will not have to wait long. Anyone interested in tropical soils will profit by the presentation of Dr. Vageler.

J. S. J.

Report on Agricultural Research in Great Britain. A survey of its scope, administrative structure and finance, and of the methods of making its results known to farmers, with proposals for future development. By the Research Group of P E P (Political & Economic Planning). P E P, 16 Queen Anne's Gate, London, S.W.1, 1938. Pp. 154. Price 8s. 6d. net.

The title of this publication is a good summary of its content. The "Political and Economic Planning" group is a nonpartisan assembly of industrialists, distributors, officers of the central and local government, scientists, university teachers, and other professionals interested in the advancement of the various phases of social and economic activities. Their findings are presented in reports; and in the case of agriculture, they have attempted, as stated by the secretary, "to show how the links between agricultural research on the one hand and agricultural policy and practice on the other might be strengthened."

The report is, in a way, incomplete, inasmuch as the reader feels that not all that the investigators wanted to say was said. And yet it is a useful service rendered, and administrators of agricultural research may find enough food for thought in all that is in the report. It may not be amiss to end this brief review with an excerpt from a paragraph on page 104: "that the gap between the farmer on the one side and the research worker and the administrator on

the other is still too wide, is clear from the cumulative evidence of the facts assembled in this report. The fundamental questions, how to bring research to closer grips with the problems of the land, and how to make farmers sufficiently alive to the benefits of research to support it spontaneously, still await a satisfactory solution."

J. S. J.

Land Utilization in China. Volume 1. By JOHN LOSSING BUCK, Professor of Agricultural Economics, The University of Nanking. The University of Nanking, Nanking, China, 1937. Agents in the United States, The University of Chicago Press, Chicago. Pp. xxxii + 494, tables 207, maps 21, figs. 57, photos 62. Price $5.

This volume, the first of a series of three, presents a study of land utilization in China as exemplified by 16,783 farms in 168 localities and 38,256 farm families in twenty-two provinces in China, 1929–1933. The survey method, used in this study, was amplified by such other data as were available for the purpose. Thus the subject of soils was treated by James Thorp, whose book *Geography of the Soils of China* represents an independent investigation outside of this survey.

The report of the study is presented in 15 chapters under the following headings: Chinese Agriculture; Agricultural Regions; Topography; Climate; Soils; The Land; Crops; Livestock and Fertility Maintenance; Size of Farm Business; Farm Labor; Prices and Taxation; Marketing; Population; Nutrition; The Standard of Living. Most of the material, 8 of the 15 chapters, was written up by Buck. The volume is beautifully illustrated.

It is a comprehensive study commensurate with its broad sponsorship by the University of Nanking, the Institute of Pacific Relations, National Economic Council, Central Bank of China, Milbank Memorial Fund, and others.

Besides the facts collected, the survey makes specific recommendations. One wonders how an invaded China could carry out the sound and well-wishing advice of this survey.

J. S. J.

Soil Science Society of America Proceedings 1938. Volume 3. Papers presented at meeting held in Washington, D. C., November 16–18, 1938. The Soil Science Society of America, G. G. Pohlman, Sec.-Treas., Morgantown, W. Va., 1939. Pp. x + 368. Price $5.

Why a volume of this kind should open with a paper on "The Application of Agronomy in Farm Planning" is perhaps not the question for a reviewer to ponder. The explanation of the anomaly perhaps lies in the announcement on page 359 that the veteran editor of the *Journal of the American Society of Agronomy*, J. D. Luckett, was elected editor of the Proceedings.

It is questionable whether papers read by title should be included in the respective sections. A list at the end of the volume would serve the purpose

of recording these. One other question may be raised: Why is the abstract (in the table of contents this is not indicated) of the Appleman and Sear paper entitled "Microbiological Aspects of the Morrow Plot Soils" placed in the section on soil chemistry?

Aside from the minor adverse criticisms suggested, this volume is well arranged and the topics are well balanced. Whatever fault one may find with the contributions, he should remember that the presentation of a paper is almost tantamount to publication, and the editorial committee is handicapped.

Like the earlier proceedings, this volume is lithoprinted, of 8.5 x 11″ size, well done, and with a sturdy and beautiful binding.

J. S. J.

Organicheskoe Veshchestvo Pochv (Organic Matter of Soils). By I. V. Tyurin. Sel'khozgiz, Leningrad, Moscow, 1937. Pp. 287. Price (unbound) 4 rubles 75 Kop. (about $1).

From the subtitle, we find that this Russian publication deals with "the role of organic matter in soil formation and soil fertility." The subtitle is indeed fitting.

This volume is unique inasmuch as it comes from the pen of Prof. Tyurin, an outstanding pedologist, forestry student, and trained chemist. Heretofore, treatises on humus were written by chemists, bacteriologists, or the old type soils man, each of whom threw some light on the subject from his particular angle. And yet, humus is primarily associated with soil-forming processes and soil fertility. Of course, Prof. Tyurin is aware of the microbiological processes as the agencies of humus formation. He devotes chapter II, about 60 pages, to the "processes responsible for the conversion of organic residues in the soil." In the remainder of the chapters (chapter I is devoted to the "composition of organic residues entering the soil") Prof. Tyurin analyzes critically the following subjects: III. Chemical composition of humus; IV. Methods of analyzing and investigating humus; V. The role of humus in the soil-forming processes; VI. The role of humus in the fertility of the soil.

A commendable feature of the presentation is its straightforwardness. The subject is not "loaded"; it is full of meat well presented with an analytical discussion of the contributions.

The author writes from first-hand experience, in close contact with the soil, with the broad outlook of the Russian school of soils and an interest which extends to the deepest roots of the science.

In congratulating the author on his achievement, the reviewer regrets that this excellent concise treatise on humus is not available in the English language.

J. S. J.

Behold Our Land. By Russell Lord. With an introduction by William Allen White. Houghton Mifflin Company, Boston, 1938. Pp. 310, illus. Price $3.

A seasoned writer of popular articles on agriculture, the author of this very

readable story of our land has fulfilled the plan and purpose of the book, which in the early pages he outlines as follows:

> I have undertaken to write a ground-line narrative of conquest and losses on the body of our land. It tells how long the weather takes to make a yielding soil; how rapidly nearly any soil, manhandled, may be lost to human use; and what, with great stretches of American soil washing or blowing out from under us, we have hastily developed as measures of defensive husbandry.
>
> The story starts with stardust and ends in the troubled present. I do not offer it as a complete account. It skips, and seeks to avoid the merely technical. It is not a history, or an almanac or a work of science. It is more nearly . . . a "profile"—an action and character sketch—which takes as its subject a living piece of land, its formation, occupation, and changing growths.
>
> The profile form permits individual interpretations which are not always susceptible to proof. But I do suggest, here and later, that other forms of erosion accompany the occupation and despoliation of a soil, and that, as a land becomes older, more crowded, more worn and wounded, accelerated erosion may extend beyond the physical surface of the country and attack the free spirit.

The book contains many excellent illustrations and a list of recommended reading.

H. B. KITCHEN

German-English Science Dictionary. By LOUIS DE VRIES, Professor of Modern Languages, Iowa State College. McGraw-Hill Book Company, Inc., New York and London, 1939. Pp. x + 473. Price $3.

This dictionary for students in the agricultural, biological, and physical sciences, containing 48,000 entries, was compiled with the collaboration of members of the graduate faculty of Iowa State College. The author points out in his introduction that the work, the first dictionary of its kind, makes no claim to completeness but includes all basic information needed in finding meanings of compound words, which "because of their compactness and conciseness, are especially adapted to the requirements of scientific literature and enlarge scientific vocabularies constantly." A convenient-sized volume, it is printed in clear readable type, which should contribute much to its usability.

H. B. K.

Statistical Technique in Agricultural Research. By D. D. PATERSON, Reader in Agriculture at the Imperial College of Tropical Agriculture, Trinidad, B.W.I. McGraw-Hill Book Company, New York and London, 1939. Pp. x + 264. Price $3.

One of the McGraw-Hill Publications in the Agricultural Sciences, this book is an elementary exposition of statistical technique for the average research worker who is interested in the practical application of the subject rather than in mathematical theory. The topics treated include the general principles of statistics, analysis of variance, goodness of fit and contingency tables, diagrams, correlation, regression, field experiments, serial and perennial crop experiments,

and recent developments in field experimentation. A bibliography, an appendix of statistical tables, and an index are also included. The book with its numerous examples of typical statistical problems encountered should be of considerable value to the research worker in designing and interpreting his experiments.

H. B. K.

Growing Plants Without Soil. The A.B.C. of Plant Chemiculture (Soilless Agriculture, Chemiculture, Water Culture, Hydroponics, Tank Farming, Sand Culture) Including Plant Growth Hormones and Their Use. By D. R. MATLIN. Chemical Publishing Company, New York, 1939. Pp. 140. Price $2.

The growing of plants in solution and sand cultures, long used by scientists for the experimental study of plant nutrition and recently developed for the growing of plants for more practical purposes, has captured the public fancy. This volume for the layman, like many other popular presentations of the subject, views the advantages of the method through rose-colored spectacles.

H. B. K.

The World Was My Garden. Travels of a Plant Explorer. By DAVID FAIRCHILD. With a foreword by Elizabeth and Alfred Kay. Charles Scribner's Sons, New York, 1938. Pp. xiv + 494, illus. Price $3.75.

In this fascinating autobiography, the author, who for more than 20 years was in charge of the Division of Plant Exploration and Introduction, of the United States Department of Agriculture, tells of his travels throughout the world in search of plants suitable for growth in America. More than 200 photographs, most of them taken by the author, illustrate this very human story of an agricultural explorer.

H. B. K.

Bacterial Metabolism. Second Edition. By MARJORY STEPHENSON, Associate of Newnham College, Cambridge, Member of the Scientific Staff of the Medical Research Council. Longmans, Green and Company, London and New York, 1939. Pp. xii + 392, illus. Price $7.50.

Substantial advances in the field of bacterial biochemistry, especially in the study of bacterial growth, bacterial fermentations, bacterial enzymes, and nitrogen fixation, and the discovery of bacterial photosynthesis necessitated the entire rewriting of *Bacterial Metabolism*, which was first published in the "Monographs on Biochemistry" series in 1930. This second edition now appears as an advanced textbook.

Applied Mycology and Bacteriology. By L. D. GALLOWAY, Imperial Mycologist, New Delhi, 1934–1937, Mycologist to British Cotton Industry Research Association, 1927–1934, and R. BURGESS, Dairy Bacteriologist to

Lancs. County Council, Microbiologist to British Woollen Industry Research Association, 1927–1935. Distributed by Chemical Publishing Company, New York (exclusive agents in North and South America for this book), 1938. Pp. x + 186. Price $4.

An elementary review of the essentials of mycology and bacteriology with particular reference to the scope and methods of economic microbiology.

Animal Life in Fresh Water. A guide to fresh-water invertebrates. By HELEN MELLANBY, Department of Zoology, University of Sheffield. With a foreword by L. E. S. Eastham, Professor of Zoology, University of Sheffield. Chemical Publishing Company, New York (exclusive agents in North and South America for this book), 1938. Pp. vii + 296, figs. 211. Price $3.50.

A guide to the identification of the common fresh-water invertebrates with notes on their habits and distribution, written in elementary terms especially for school pupils.

An Introduction to Industrial Mycology. By GEORGE SMITH, Research Demonstrator, Department of Biochemistry, London School of Hygiene and Tropical Medicine. With a foreword by Harold Raistrick, University Professor of Biochemistry, London School of Hygiene and Tropical Medicine. Edward Arnold & Co., London, 1938. Pp. xii + 302, figs. 127. Price 16s net.

A textbook, for those beginning the study of "molds" rather than of fungi in general, consisting principally of descriptions and illustrations of genera of molds occurring in industrial products.

A Fundamental Approach to Bacteriology. By COURTLAND SAWIN MUDGE, Dairy Bacteriologist in the Experiment Station and Associate Professor of Dairy Industry, University of California, and FLOYD RUSSELL SMITH, Junior Dairy Bacteriologist in the Experiment Station and Instructor in Dairy Industry, University of California. J. W. Stacey, Inc., San Francisco, 1939. Pp. ix + 266, figs. 17.

A laboratory guide for instructors and students in general bacteriology.

The Biology of Bacteria. An Introduction to General Microbiology. Second Edition. By ARTHUR T. HENRICI, Professor of Bacteriology, University of Minnesota. D. C. Heath and Company, New York. Pp. xiii + 494, figs. 112. Price $3.60.

In the revision of this textbook, two new chapters on ecology of bacteria have been added.

Research and Statistical Methodology Books and Reviews 1933–1938. Edited by OSCAR KRISEN BUROS. Rutgers University Press, New Brunswick, 1938. Pp. viii + 100. Price $1.25.

A collection of excerpts from critical reviews of research and statistical

methodology books and monographs published between January 1, 1933 and November 15, 1938.

Plant Physiology. By BERNARD S. MEYER, Associate Professor of Botany, the Ohio State University, and DONALD B. ANDERSON, Professor of Botany, College of Agriculture and Engineering of the University of North Carolina. D. Van Nostrand Company, New York, 1939. Pp. x + 696, figs. 151. Price $4.50.

A textbook for colleges and universities, designed to serve as the basis for a conventional recitation course or as a background source of information for student reading in connection with lecture-discussion courses.

Introduction to Floral Mechanism. By S. G. JONES. Chemical Publishing Co., Inc., New York, 1939. Pp. xi + 274, illus. Price $4.

This elementary textbook on floral morphology, by a member of the Department of Botany at the University of Glasgow, gives due consideration to the increasing emphasis on cytology and genetics in botany. The book is well supplied with illustrations, principally from original drawings by the author.

The Structure of Economic Plants. By HERMAN E. HAYWARD, Professor of Botany, The University of Chicago. The Macmillan Company, New York, 1938. Pp. x + 674, figs. 340. Price $4.90.

The main part of this work, following the introductory chapters on general plant anatomy, deals with the structure and developmental anatomy of the economic plants, corn, wheat, onion, hemp, beet, radish, alfalfa, pea, flax, cotton, celery, sweet potato, white potato, tomato, squash, and lettuce, each selected on the basis of economic importance, suitability as a representative of the family to which it belongs, and intricacy of its anatomical and morphological detail. Important fruit crops have been omitted because of the author's plans to include them in a second volume.

Die Bierhefe als Heil-, Nähr- und Futtermittel (Brewer's Yeast as Medicine, Food, and Fodder). Second, Revised and Enlarged, Edition. By JULIUS SCHÜLEIN. Theodor Steinkopff, Dresden and Leipzig, 1938. Pp. viii + 262, figs. 22, tables 10. Price RM 9.

Bergey's Manual of Determinative Bacteriology. A Key for the Identification of Organisms of the Class Schizomycetes. By DAVID H. BERGEY, ROBERT S. BREED, and E. J. D. MURRAY. Williams & Wilkins Co., Baltimore, Md. Pp. ix + 78. Price $1.

This is a reprint from the fifth edition of the Manual.

Plant Growth-Substances. Their chemistry and applications, with special reference to synthetics. By HUGH NICOL, Assistant Bacteriologist, Roth-

amsted Experimental Station. Distributed by Chemical Publishing Company, New York, 1938. Pp. xii + 106, illus. Price $2.

Technical, for the most part, but containing two chapters for the layman.

Muir's Bacteriological Atlas. Second Edition. Atlas enlarged and text rewritten by C. E. VAN ROOYEN, M. D., Halley Stewart Research Fellow and Lecturer in Bacteriology, University of Edinburgh. William Wood & Company, Baltimore, Maryland, 1937. Pp. xvi + 90, pl. 83. Price $5.25.

In the second edition of this atlas for medical undergraduates and others engaged in the study of practical bacteriology, the text has been rewritten, and twenty-six new colored plates illustrating the morphology of thirty-two different microorganisms have been added. Plates illustrating the elementary and inclusion bodies of various virus infections are a feature of this edition.

Modern Sewage Disposal. Edited by LANGDON PEARSE. Federation of Sewage Works Associations, 654 Madison Avenue, New York, N. Y. Pp. 372, illus.

This anniversary volume, issued to commemorate ten years of service by the Federation of Sewage Works Associations, is, according to the forward, "an effort to replace a convention of world-wide workers by a contributed set of papers along unusual topical lines." The papers are grouped under the following main headings: Sewage Treatment Practice, Sewage Research, Regional and National Aspects, and Industrial Wastes.

Cattle Fodder and Human Nutrition. With Special Reference to Biological Nitrogen Fixation. By AI TTURI I. VIRTANEN, Professor at the Technical University, Director of the Biochemical Institute, Helsinki. Cambridge University Press, Cambridge, 1938. Pp. 108, illus. Price $2.25.

This book contains four lectures on the following subjects: The Mechanism of the Biological N-Fixation; The Symbiosis of the Leguminous Plants with the Legume Bacteria; The Production of Vitamins in Agriculture, with Special Reference to Human Nutrition; and The A.I.V. Method for the Preservation of Fresh Fodder and its Importance in Agriculture. A general survey is added in which the connection between the subject matter of the different lectures is illustrated and the practical importance in agriculture and human nutrition is discussed.